NEW

HOW IT WORKS

BOOK OF

EXTREME WEATHER

AND THE SCIENCE BEHIND EARTH'S FORCES OF NATURE

EXCLUSIVE MICHAEL FISH INTERVIEW

- FIRESTORMS • TYPHOONS • LIGHTNING • CYCLONES

WELCOME TO

HOW IT WORKS
BOOK OF

EXTREME WEATHER

The weather is something that we typically talk about all the time, but beyond the drizzle and chill in the air, what do we really know about the weather of the Earth that we live on? Extremes affect people every day, with lightning strikes, hurricanes, monsoons and floods, but even the science and technology play a part in our every day lives. In this book we aim to show you the most monstrous weather – from the deadly heatwaves and cyclones – to the science behind how forecasters predict the weather. We speak to Michael Fish about his career at the UK Met Office and that fateful storm of 1987. Take a look at the extraordinary sights and what Earth can behold. Enjoy the book.

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Imagine Publishing Ltd
Richmond House
33 Richmond Hill
Bournemouth
Dorset BH2 6EZ
☎ +44 (0) 1202 586200
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Twitter: @Books_Imagine
Facebook: www.facebook.com/ImagineBookazines

Publishing Director
Aaron Asadi

Head of Design
Ross Andrews

Production Editor
Jen Neal

Senior Art Editor
Greg Whitaker

Designer
David Lewis

Printed by
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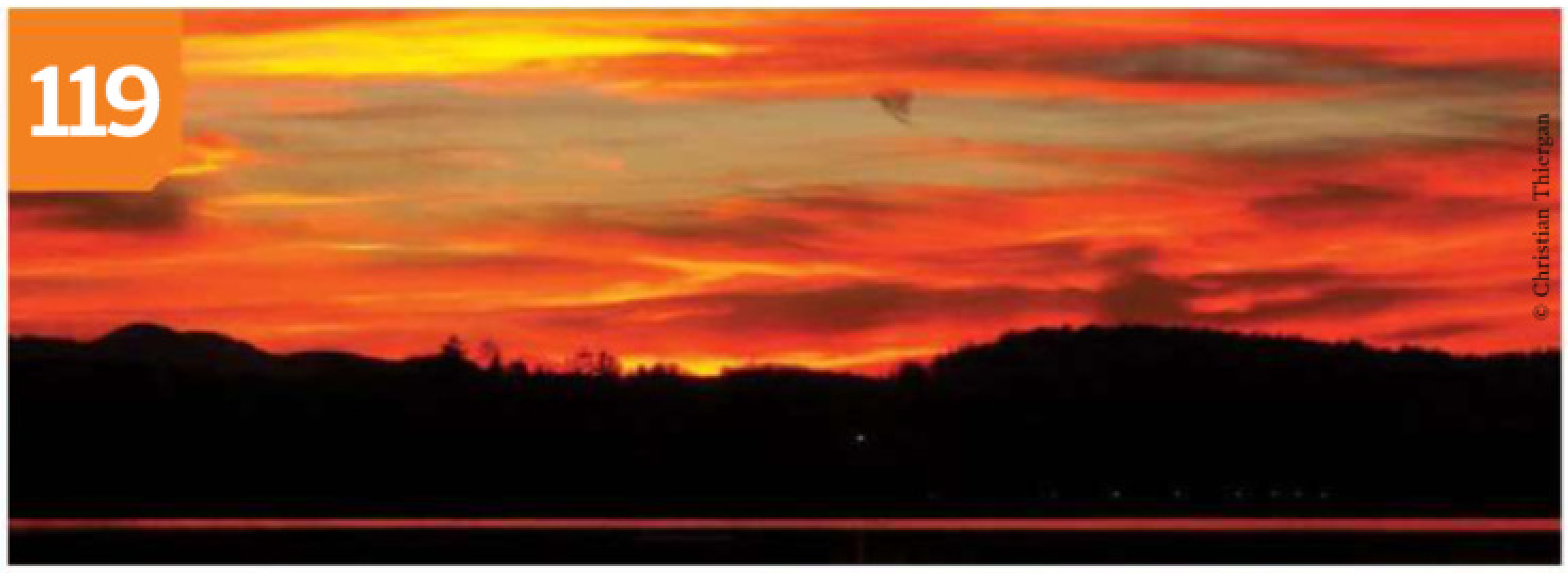

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EXTREME WEATHER

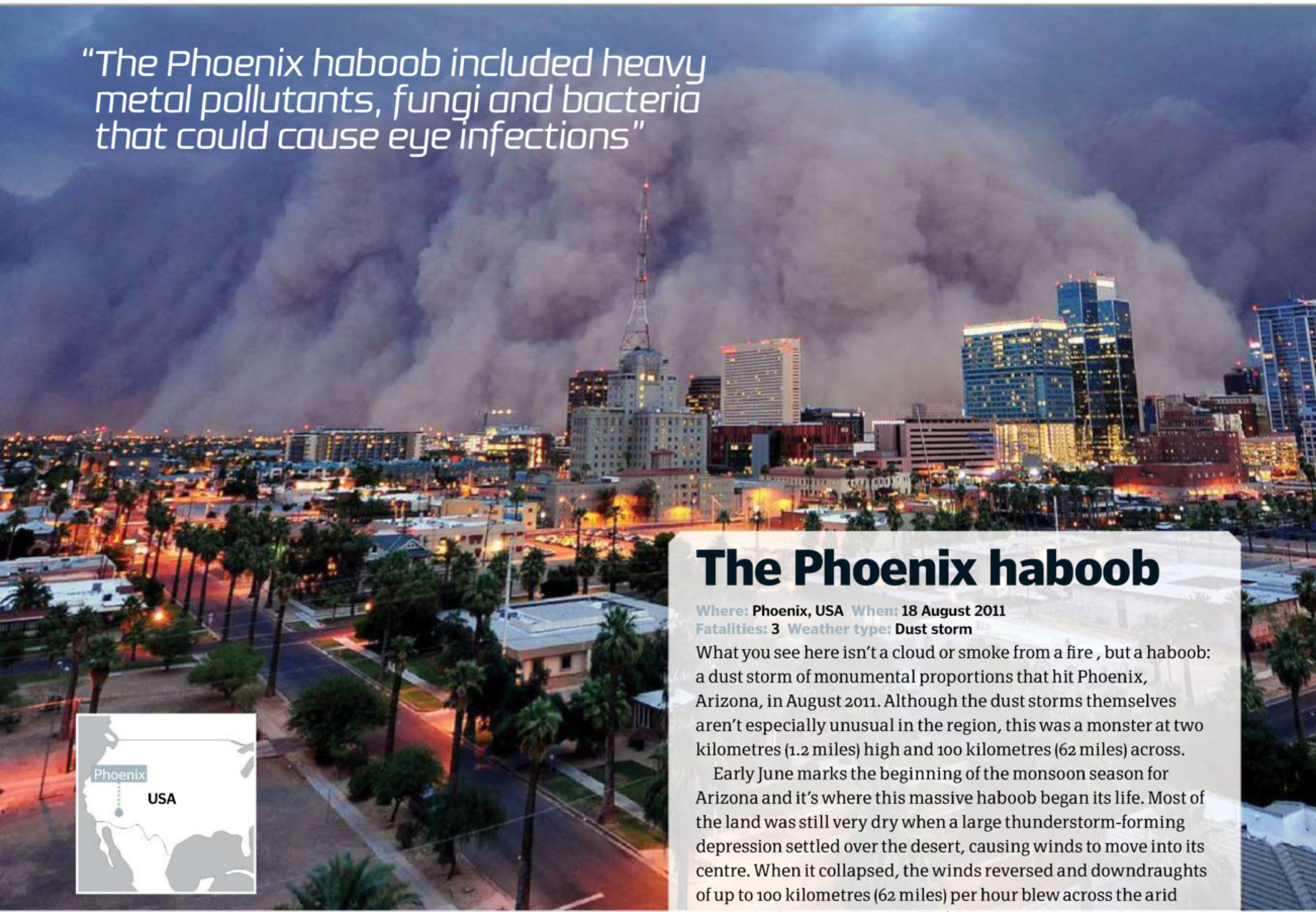
Uncovering the origins of the most savage meteorological phenomena that the world has ever seen

'A butterfly flaps its wings in China and a hurricane hits Florida' – or at least so goes the well-known saying. That's usually a metaphorical expression that describes the Butterfly Effect, the idea that the sequence of events which leads to an eventual outcome is so chaotic and so far removed from its source that it's near impossible to determine. In the case of predicting the weather, however, it can be taken literally. Though meteorologists might not be quite at the stage of pinning a specific weather pattern down to the movements of an insect, they have got the science of weather prediction down to a fine art. But they do get it wrong sometimes.

In mid-October 1987, UK meteorologists predicted a spot of bad weather would hit the south coast of Britain but the deepening depression over the continent would progress no farther than the English Channel. As it turned out, the depression not only moved on to the UK mainland, but also plummeted to a low of 953 millibars at the centre of what would later be christened the 'Great Storm of 1987'. Indeed, it was the worst tempest to hit northern Europe in nearly 300 years, with winds gusting up to 196 kilometres (122 miles) per hour in the UK and even faster in France. It downed around 15 million trees, caused nearly £5 billion ($8 billion) worth of damage and forced the National Grid to shut down the power supply to London.

As a force 11/12 storm on the Beaufort scale at worst, the Great Storm of 1987 would be the equivalent of a category 1 hurricane or a severe tropical storm. It's weather that subequatorial regions are well used to, if not prepared for, but which is unheard of in more temperate climes. The fortunate thing about these freak occurrences is that, more often than not, they can be traced to a source. So even if we can't do anything to stop it happening again, scientists are more informed of the signs of extreme weather and perhaps we can be more prepared the next time a mega-storm hits.

In this eight-page feature, we delve into some of the most extreme examples of weather from across the globe, what makes them so weird, the meteorological records they broke, the damage they caused, as well as the human cost. Where did the freak storms come from? What conditions gave rise to those temperatures and will anyone ever see rain like that again? **HIW** traces the floods, droughts, winds, rains and more back to their source to find out exactly what took them to a whole other level.



"The Phoenix haboob included heavy metal pollutants, fungi and bacteria that could cause eye infections"

The Phoenix haboob

Where: Phoenix, USA **When:** 18 August 2011
Fatalities: 3 **Weather type:** Dust storm

What you see here isn't a cloud or smoke from a fire , but a haboob: a dust storm of monumental proportions that hit Phoenix, Arizona, in August 2011. Although the dust storms themselves aren't especially unusual in the region, this was a monster at two kilometres (1.2 miles) high and 100 kilometres (62 miles) across.

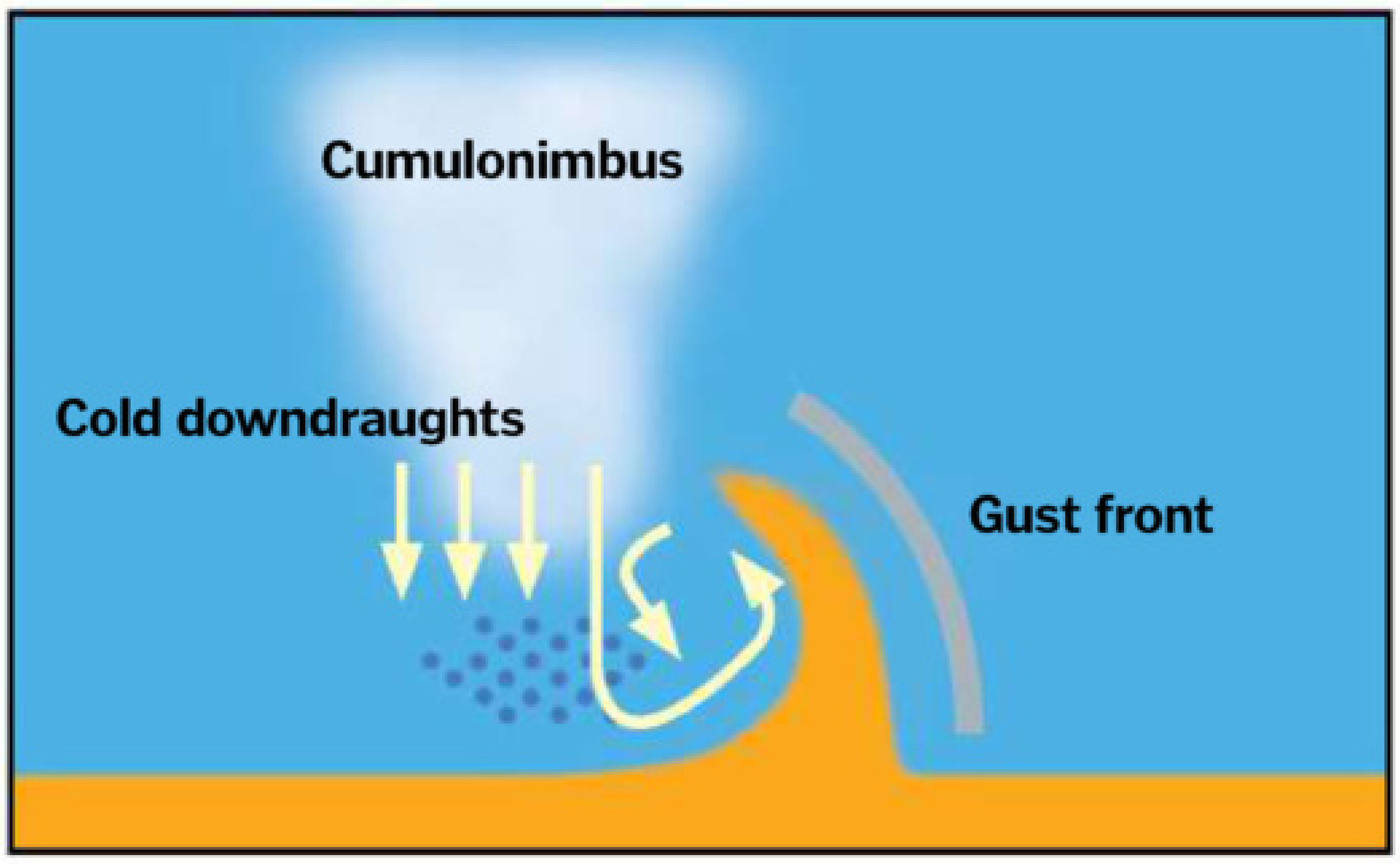
Early June marks the beginning of the monsoon season for Arizona and it's where this massive haboob began its life. Most of the land was still very dry when a large thunderstorm-forming depression settled over the desert, causing winds to move into its centre. When it collapsed, the winds reversed and downdraughts of up to 100 kilometres (62 miles) per hour blew across the arid region, kicking up a huge wall of dust that swept over the city.

Haboobs occur in several desert areas, including the Middle East and Australia. They're not particularly dangerous, but the dust gets everywhere and they can leave a covering of up to 0.3 metres (one foot) of sand. The Phoenix haboob included additional hazards in the form of heavy metal pollutants, fungi and bacteria that could cause eye infections and lung diseases.

Sudan sees a lot of haboobs – in fact, it is where the name originates

Cool fact

They may just be dust, but haboobs can take down power lines, jam electrical devices and play havoc with aircraft.



© Getty

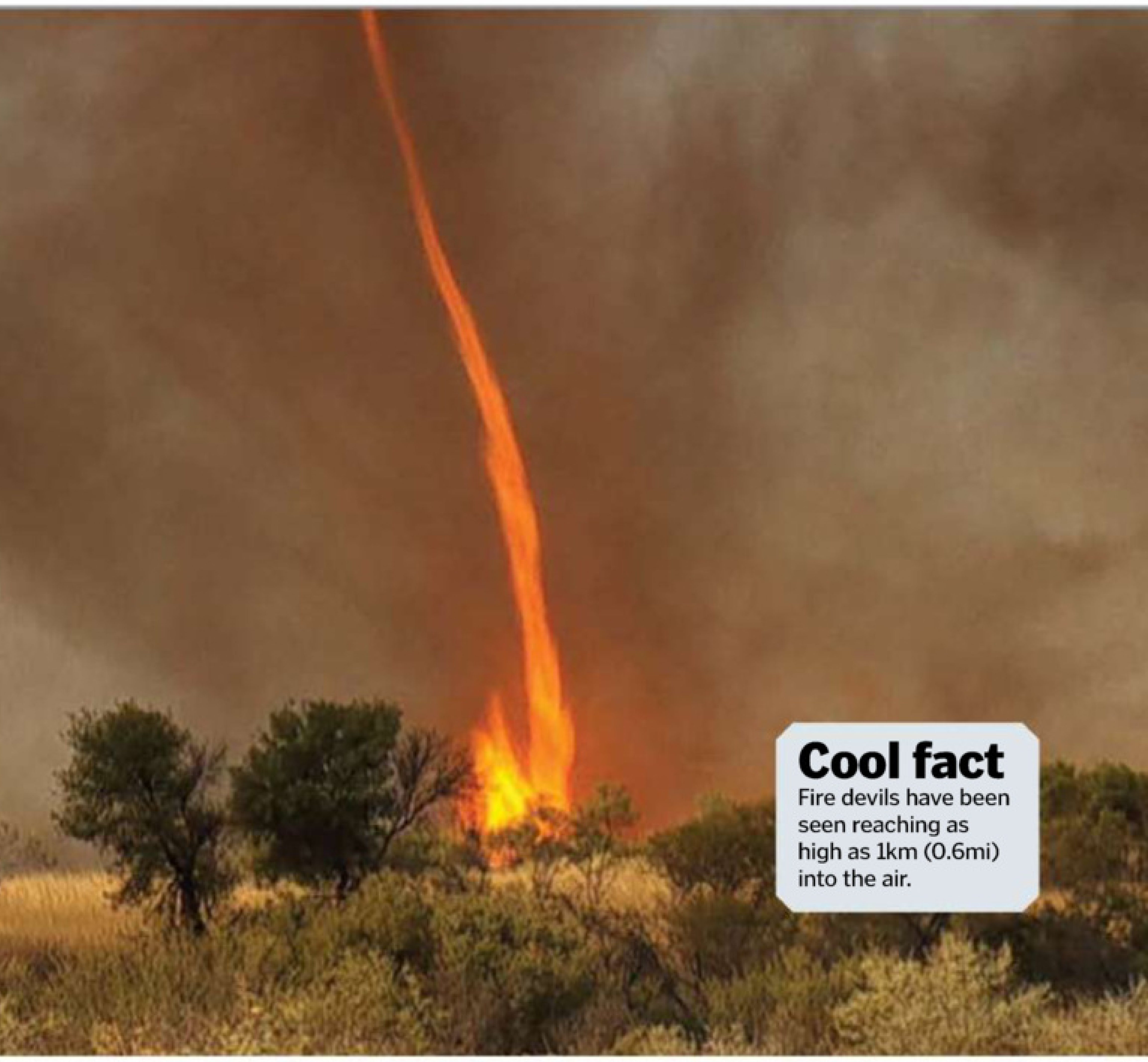
Australian fire devil

Where: Alice Springs, Australia **When:** 16 September 2012
Fatalities: 0 **Weather type:** Fire devil

They're more akin to dust devils than tornadoes, but the flaming columns that form fire devils are much rarer than either. They're hardly ever seen and rarely last long, which makes this most recent event in the Australian outback so much more incredible.

Filmmaker Chris Tangey had been working in the Alice Springs area when he was confronted with this 30-metre (100-foot) pillar of flame. Not only did it 'sound like a fighter jet', but it lasted nearly 40 minutes, giving Tangey ample time to video it and take photographs.

Fire devils can occur when a column of warm air forcing its way up either comes in contact with a fire or conditions are right for it to create a spark. In the case of this fire devil, a bush fire that had raged for a week, plus an extended dry spell since April 2012, along with a perfectly still day were ripe conditions for the fire tornado.



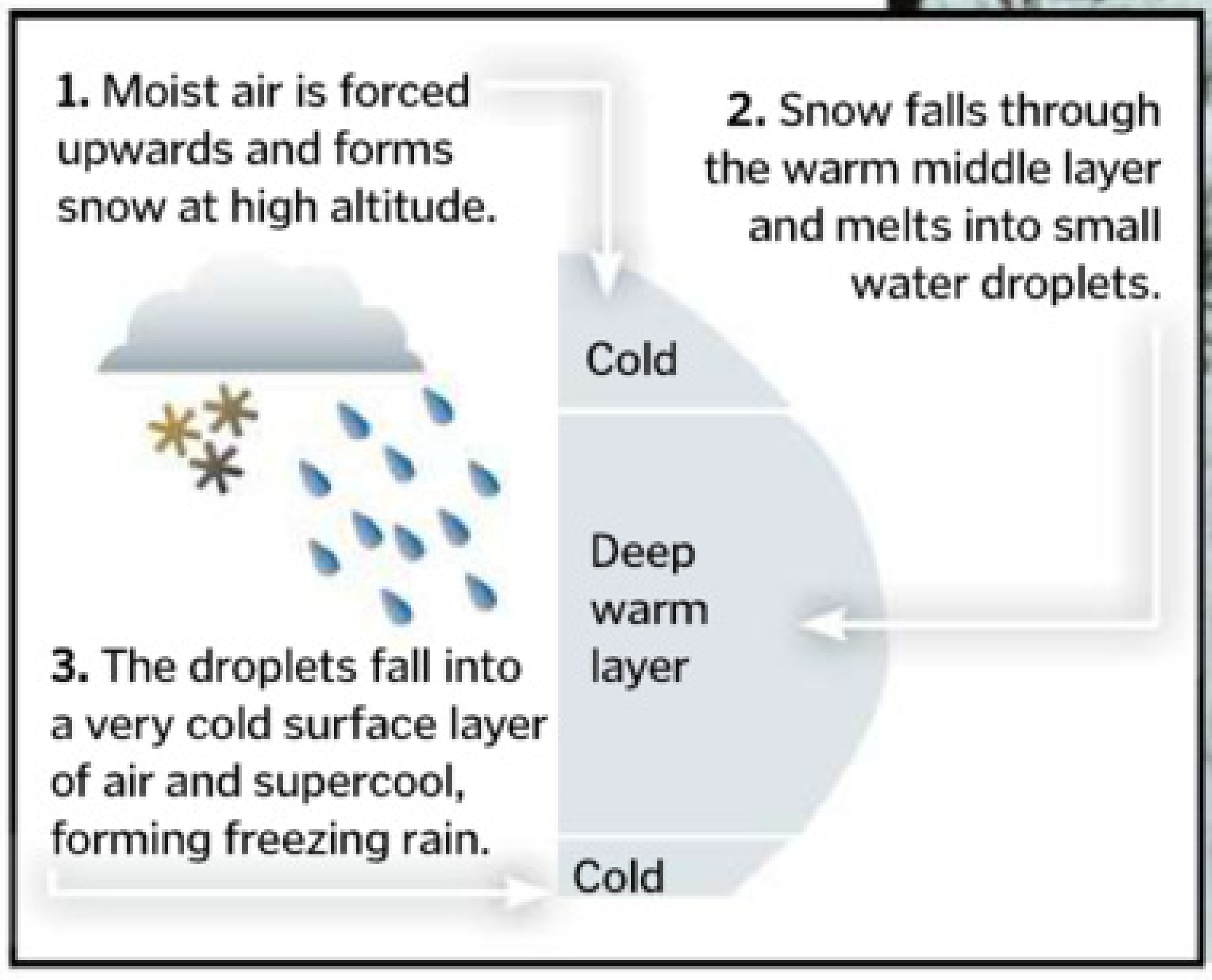
Cool fact
Fire devils have been seen reaching as high as 1km (0.6mi) into the air.

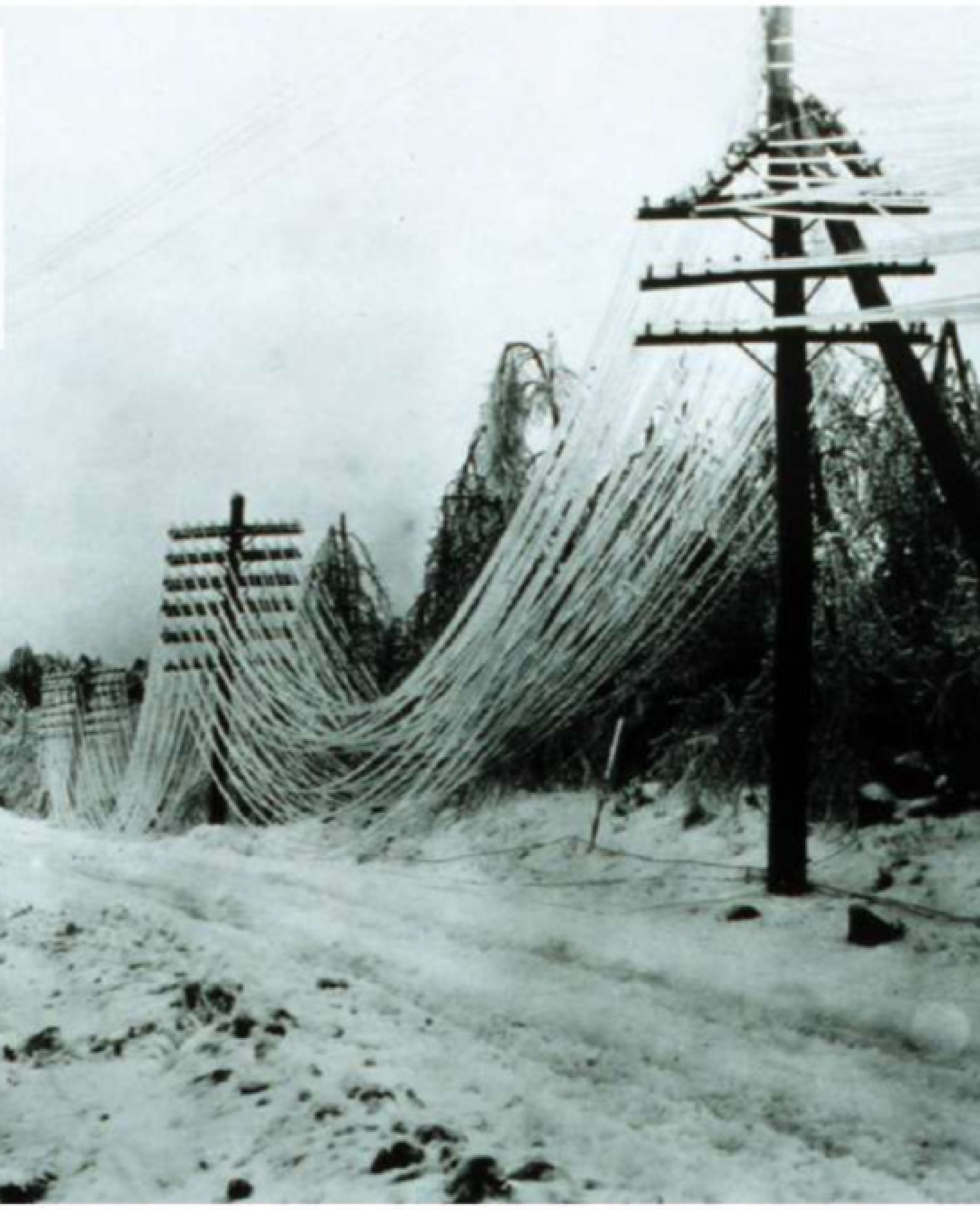
The North American Ice Storm of 1998

Where: North-east America **When:** 7 January 1998 **Fatalities:** 55
Weather type: Ice storm **Damage:** $6 billion (£3.7 billion)

Ice storms are common on the east coast of the US and Canada. The infrastructure is generally prepared for the havoc these storms can wreak, but winter 1998 brought with it the most crippling ice storm in living memory.

By 5 January 1998 it was clear eastern North America was in for a cold spell. An area of unusually high pressure was sitting over the Atlantic, trapping several weather systems on the land. Arctic air was being held at the surface in this area, while a front of low pressure was feeding it with warm, moist air from the Gulf of Mexico. The result was 12.7 centimetres (five inches) of freezing rain that fell over 80 hours, crystallising on anything it touched, taking down power lines, felling trees and making roads impassable everywhere. One of the worst-hit cities was Montréal in Québec.


1. Moist air is forced upwards and forms snow at high altitude.
2. Snow falls through the warm middle layer and melts into small water droplets.
3. The droplets fall into a very cold surface layer of air and supercool, forming freezing rain.
Cold
Deep warm layer
Cold



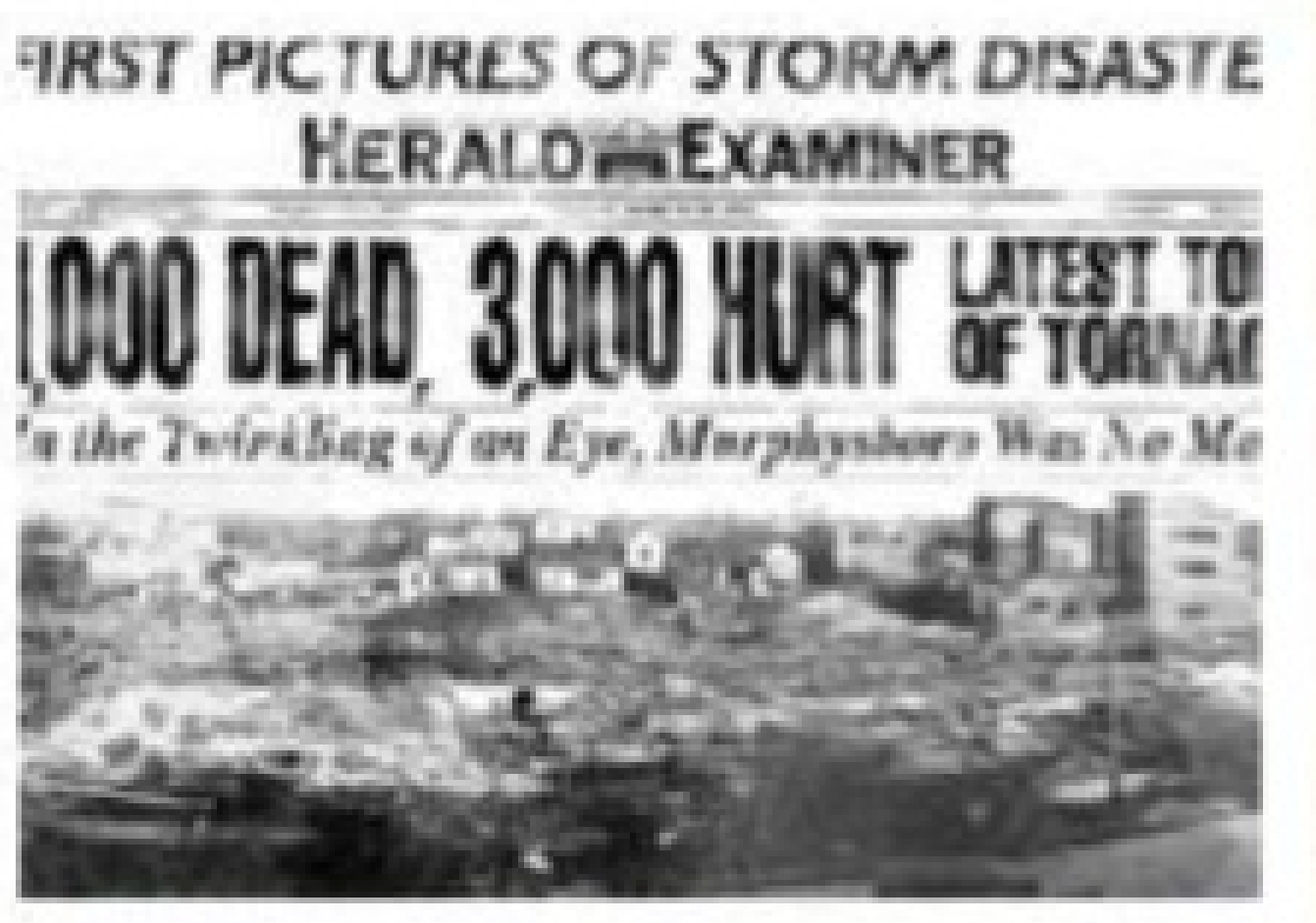
> *"The River Thames in London totally froze over for two months"*

The Tri-State Tornado

Where: Southern USA **When:** 18 March 1925 **Fatalities:** 695 (confirmed)
Weather type: F5 tornado **Damage:** $16.5m ($1.4bn/£873m today)

The deadliest tornado in US history was part of a tornado outbreak that struck the southern states in spring 1925. It touched down in Missouri and tracked north-east through Illinois and on to Indiana where it dissipated. In its wake the F5 monster – the highest possible rating on the Fujita scale – destroyed 15,000 homes and killed hundreds of people. It could move at 110 kilometres (70 miles) per hour, travelled 352 kilometres (219 miles) and, because it was so massive, it appeared as an enormous black, ground-hugging cloud, rather than the characteristic funnel shape.

The Tri-State Tornado was born out of a cold low-pressure system that had been following what we now know is the jet stream, down from Canada, along the Texas-Oklahoma border and into Missouri. It's here that it hit a warm front from the Gulf of Mexico and conditions were made perfect for a tornado outbreak. Judging by the speed the Tri-State Tornado travelled at, it's likely the winds in the jet stream were particularly strong at the time.


IRST PICTURES OF STORM DISASTE
HERALD EXAMINER
1,000 DEAD, 3,000 HURT LATEST TO OF TORNA
In the Twinkling of an Eye, Murphysboro Was No Mo

The Little Ice Age

Where: Northern Europe **When:** 1350-1850
Damage: N/A **Weather type:** Global cooling

The 'Little Ice Age' wasn't a true ice age, but a period of significant cooling that took place worldwide (though it was felt most keenly in northern Europe) over the course of 500 years. It was punctuated by several brief warming periods with the coldest period manifesting itself in the late-17th and early-18th centuries. It's during the winters over this period that the European landscape completely changed to something evocative of what might happen if a real ice age occurred. Over the bitter winter of 1683-1684, the River Thames in London completely froze over for two months and in Switzerland entire villages were lost to advancing glaciers.

Evidence suggests that this period of global cooling could have been caused by a number of factors combined. Volcanic activity around Indonesia in the 13th century had a likely long-term effect, while a very slight shift in the Earth's orbit at this time definitely contributed. The dips in this cooling period also coincided with minimums in solar activity.

1931 Yellow River flood

Where: China **When:** July-November 1931 **Fatalities:** Up to 4 million
Weather type: Flood **Damage:** Unknown billions

In 1931, China experienced one of the deadliest natural disasters ever. Having had a two-year drought, China's three big rivers burst their banks over three months: the overflowing Yangtze and Huai drowned nearly half a million people between them, but casualty estimates of the Yellow River flood are as high as 2 million. Millions more faced starvation and sickness from waterborne diseases like cholera. Both the human and financial costs are hard to calculate. No single factor can be blamed for this tragic event, but it's believed that large amounts of meltwater from a particularly snowy winter, combined with heavy spring rain, began the abnormal flooding season. This was followed by no less than seven torrential typhoons in July alone, when China usually only sees two in a whole year.

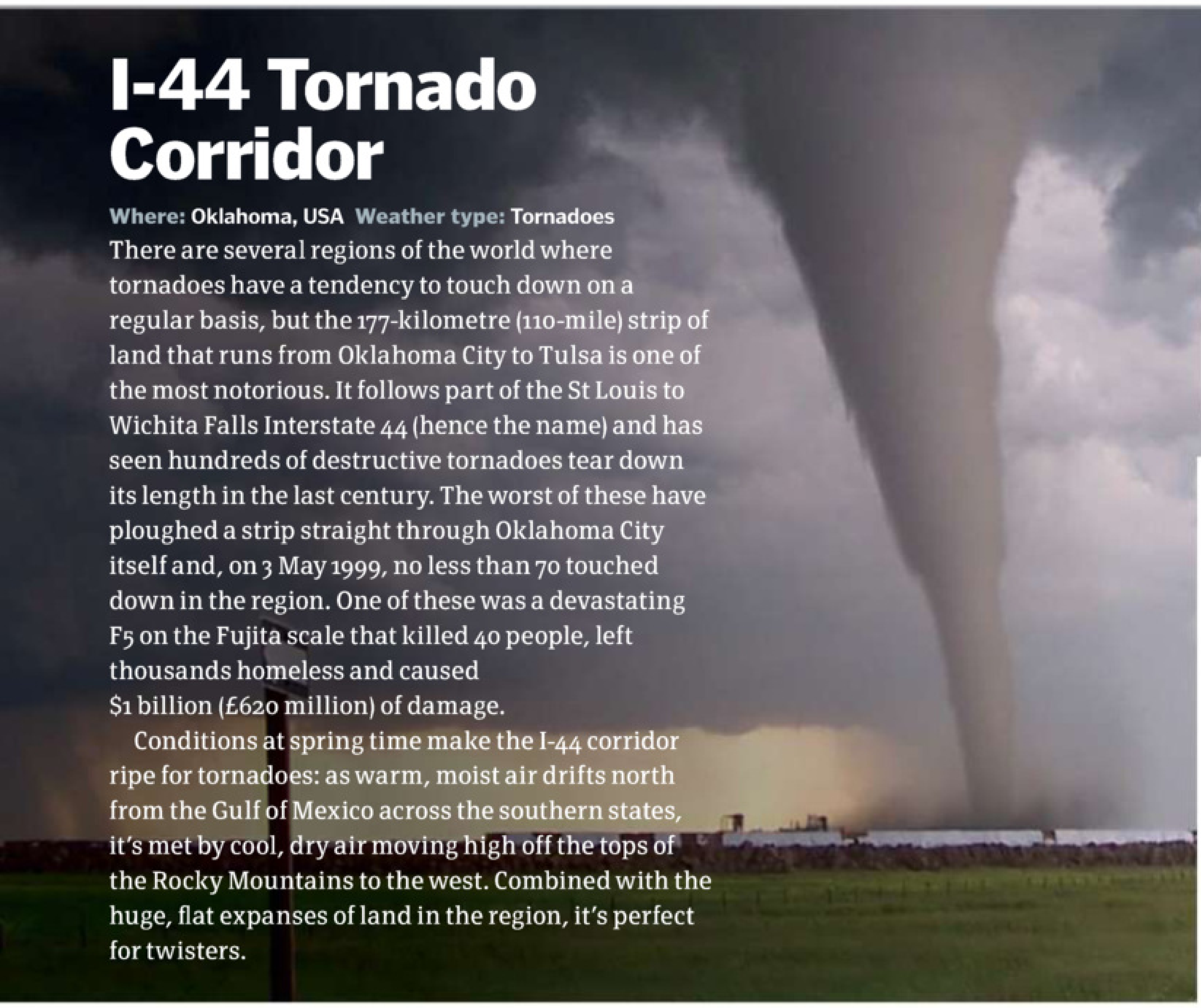
Cool fact

The Yellow River has several dams, which have been broken in the past to use the river as a weapon against enemy armies.

These days, Yellow River flood relief comes in the form of a controlled burst from the Xiaolangdi Dam

© NOAA; SWNS; Corbis

I-44 Tornado Corridor



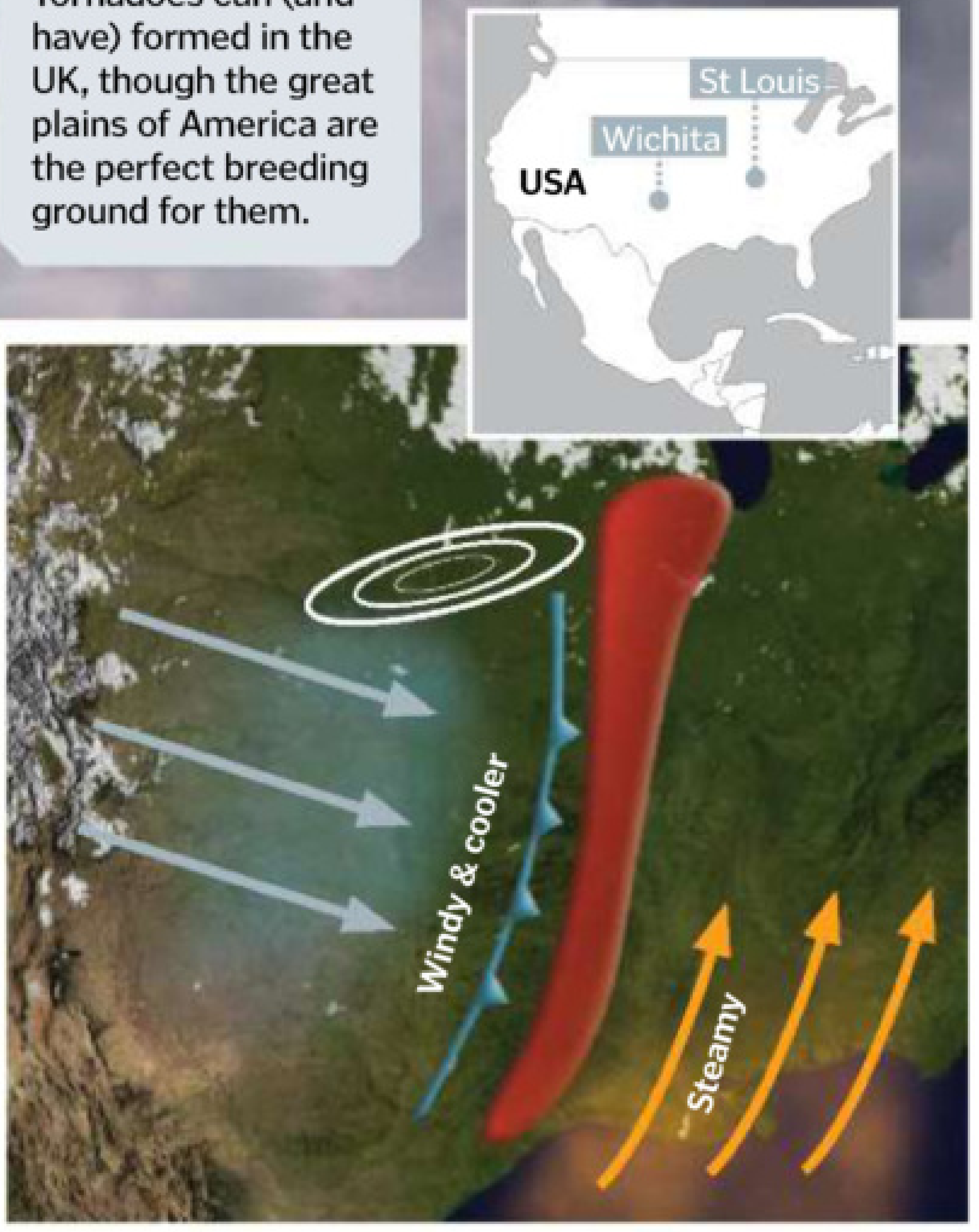
Where: Oklahoma, USA **Weather type:** Tornadoes

There are several regions of the world where tornadoes have a tendency to touch down on a regular basis, but the 177-kilometre (110-mile) strip of land that runs from Oklahoma City to Tulsa is one of the most notorious. It follows part of the St Louis to Wichita Falls Interstate 44 (hence the name) and has seen hundreds of destructive tornadoes tear down its length in the last century. The worst of these have ploughed a strip straight through Oklahoma City itself and, on 3 May 1999, no less than 70 touched down in the region. One of these was a devastating F5 on the Fujita scale that killed 40 people, left thousands homeless and caused $1 billion (£620 million) of damage.

Conditions at spring time make the I-44 corridor ripe for tornadoes: as warm, moist air drifts north from the Gulf of Mexico across the southern states, it's met by cool, dry air moving high off the tops of the Rocky Mountains to the west. Combined with the huge, flat expanses of land in the region, it's perfect for twisters.

Cool fact

Tornadoes can (and have) formed in the UK, though the great plains of America are the perfect breeding ground for them.

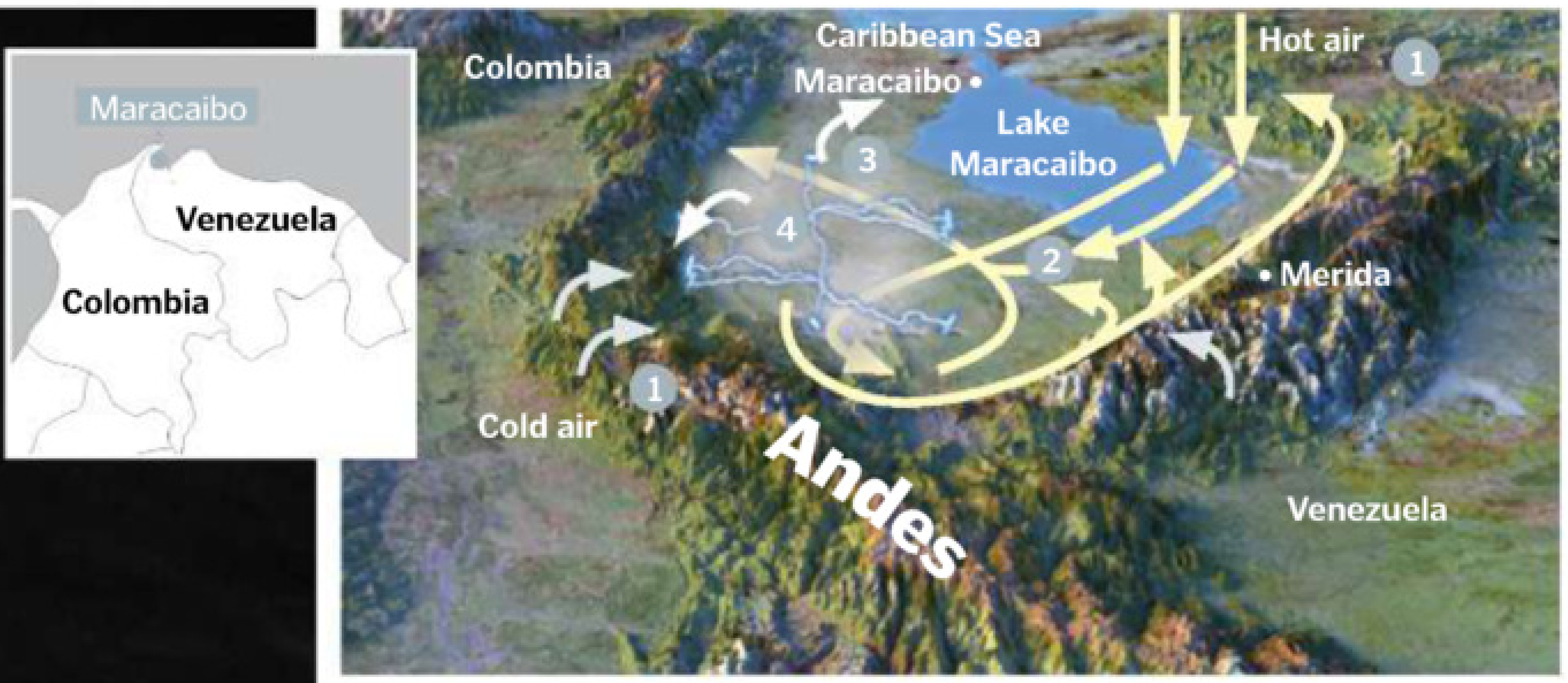


Lighthouse of Maracaibo

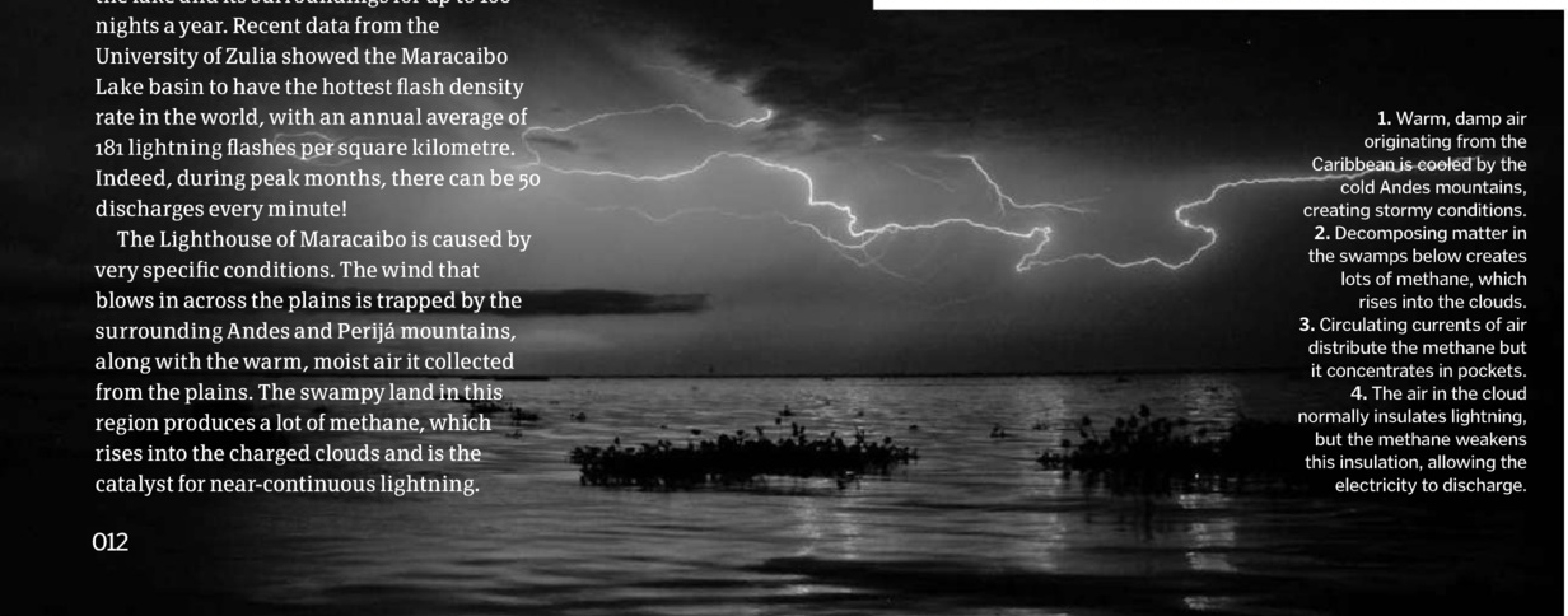
Where: Lake Maracaibo, Venezuela
Weather type: Lightning

There's a lightning storm over Lake Maracaibo that has raged on and off for centuries. This unique phenomenon can be seen from many miles away, illuminating the lake and its surroundings for up to 160 nights a year. Recent data from the University of Zulia showed the Maracaibo Lake basin to have the hottest flash density rate in the world, with an annual average of 181 lightning flashes per square kilometre. Indeed, during peak months, there can be 50 discharges every minute!

The Lighthouse of Maracaibo is caused by very specific conditions. The wind that blows in across the plains is trapped by the surrounding Andes and Perijá mountains, along with the warm, moist air it collected from the plains. The swampy land in this region produces a lot of methane, which rises into the charged clouds and is the catalyst for near-continuous lightning.



1. Warm, damp air originating from the Caribbean is cooled by the cold Andes mountains, creating stormy conditions.
2. Decomposing matter in the swamps below creates lots of methane, which rises into the clouds.
3. Circulating currents of air distribute the methane but it concentrates in pockets.
4. The air in the cloud normally insulates lightning, but the methane weakens this insulation, allowing the electricity to discharge.



Cool fact

Continental drift opened Drake Passage 41 million years ago, creating the Antarctic Circumpolar Current which helps to keep the continent cold.

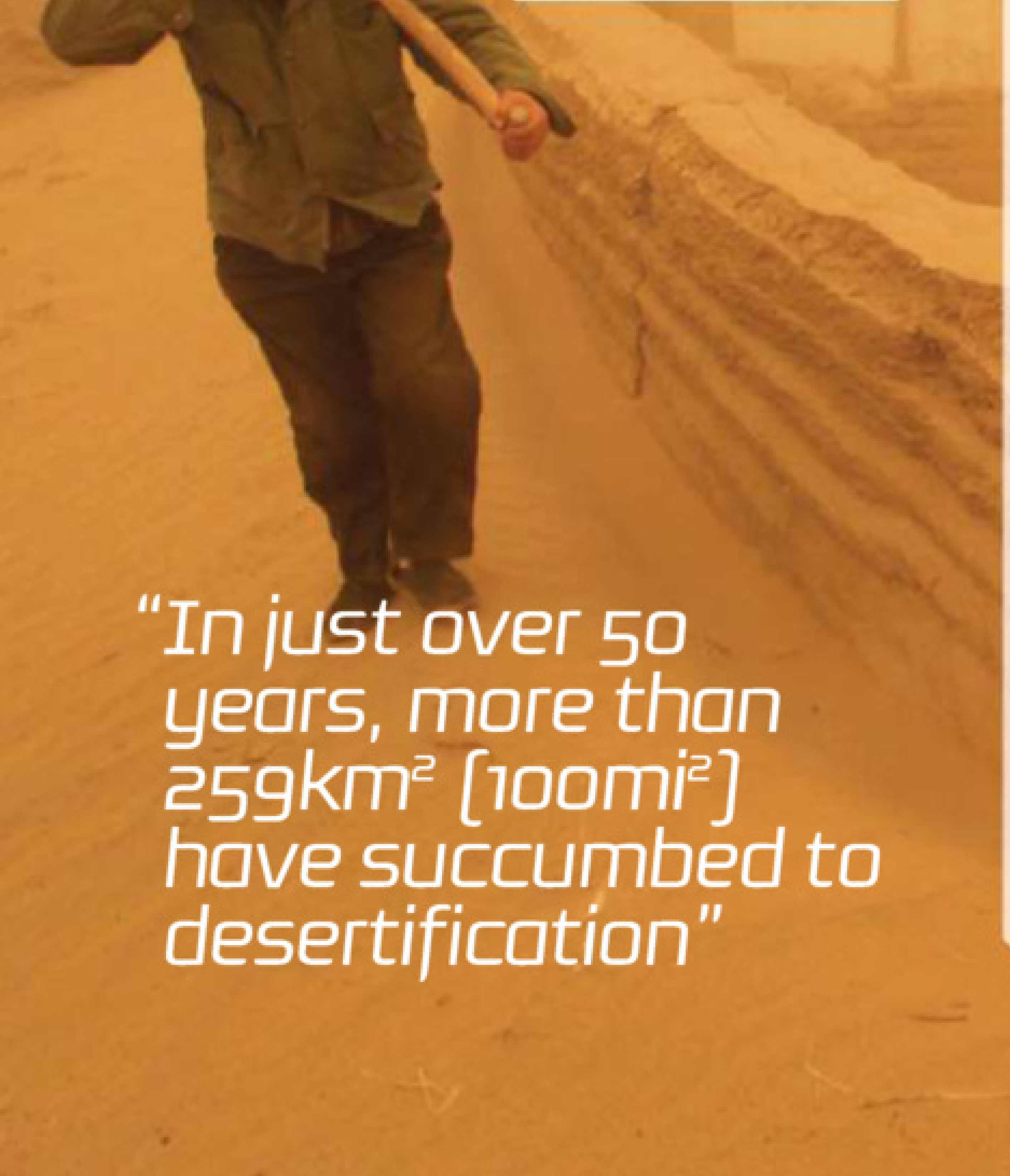
The storms of Drake Passage

Where: South Atlantic/Pacific
Weather type: Sea storm

It's known as the roughest patch of ocean in the world ever since English privateer and explorer Sir Francis Drake gave it his name in 1578. Drake Passage is a stretch of water 800 kilometres (500 miles) wide from the southern tip of South America to the frosty islands that surround Antarctica.

These seas are rarely anything less than choppy and are frequently challenging even the most seasoned navigators and sailors. The wind in alternate passages from the southern Atlantic into the Southern or Pacific Oceans is often too strong to make any headway against, so Drake Passage is usually chosen as the lesser of two evils despite its treacherous waters.

The Antarctic Circumpolar Current that travels swiftly through Drake Passage is made rough by the high winds that move from west to east at this latitude, creating waves that are frequently ten metres (32 feet) or higher.



"In just over 50 years, more than 259km² (100mi²) have succumbed to desertification"

The Creeping Sandbox

Where: Gansu province, China
Weather type: Sand storm

To most of us, a desert is an arid region that is relatively fixed. We don't think of them as growing entities that can overwhelm communities in our lifetime, but that's exactly what's happening to the once fertile Minqin Oasis region of China.

This farming community is being rapidly evicted by two deserts that sandwich it: the Tengger to the south-east and Badain Jaran to the north-west. In just over 50 years, more than 259 square kilometres (100 square miles) have succumbed to desertification by the sands that advance at ten metres (32 feet) a year. While arable land has decreased from 932 to 155 square kilometres (360 to 60 square miles), the population has more than doubled, so farmers constantly need to relocate. Part of the reason Minqin is being swallowed up so fast is a long-term drought in the area and because the oasis's life source – the Shiyang River – has been diverted farther upstream.

Airborne invaders

Australian Dust Storm

2009 saw a dust storm of enormous proportions engulf the Australian territories of New South Wales and Queensland. It was nearly 3,500 kilometres (2,175 miles) long at its peak. Meteorologists suspect that a low-pressure front and 100-kilometre (62-mile)-per-hour winds picked up dust from the dry interior and carried it to the coast.

Réunion Island rains

The island of Réunion, east of Madagascar, boasts seven of the world's top ten rainfall records, including: 182.4 centimetres (71.8 inches) in 24 hours and 5.7 metres (18.63 feet) in ten days.

Meschera money storm

In the summer of 1940, a shower of 1,000 or so 16th-century silver coins reportedly dropped on the Meschera region of Russia during a violent storm. It's suspected that the coins were from a buried treasure hoard that was ripped out of the ground, perhaps by a falling tree, and carried up by high winds before being dropped.

1972 Iran Blizzard

Freezing temperatures and storms in southern Iran resulted in up to eight metres (26 feet) of snow blanketing more exposed areas, killing 4,000 people and burying several villages entirely.

© Corbis; Getty; CMC of Universidad de Zulia, Daniella Dearden; Mrcricket48; NASA

Cyclones, typhoons and hurricanes

Devastating wind storms come with many names, but do they differ in any way?

What's the difference between a cyclone, a typhoon and a hurricane? In fact, there is none. These are the regional names given to a certain type of violent storm. So, cyclones occur in the south Pacific and Indian Ocean, typhoons in the north-west Pacific, while in the Atlantic or north-east Pacific they're called hurricanes.

These violent storms are characterised by extremely strong winds that can gust in excess of 200 kilometres (125 miles) per hour, torrential rain, floods and extremely high seas. At the centre of these storms is an 'eye', a circular region typically between 30 and 65 kilometres (20 and 40 miles) wide that moves with the storm and marks the low point of the atmospheric depression. The eye itself is cold, deceptively calm and sunny, though the strongest winds and thunderstorms encircle its border, forming the eyewall.

The ingredients for a storm of this type include an existing weather system combined with warm seas, which is why they only ever occur in subequatorial latitudes. These storms don't form within 500 kilometres (300 miles) of the equator because they rely on the swirling Coriolis effect for its rotation, which diminishes to zero the closer you are to the equator. With rare exceptions, neither do they form in waters with a surface temperature colder than around 26 degrees Celsius (80 degrees Fahrenheit), which rules out much of the rest of the world.

As with many types of extreme weather, the size and intensity don't necessarily reflect its notoriety: the typhoon, for example, is typically several times bigger than its Atlantic cousin, the hurricane. But many smaller hurricanes have achieved a higher profile simply because they made landfall and devastated the highly populated southern states of the US.

Key

Cyclones, hurricanes and typhoons form in the warm waters near the equator from where they circulate away. Their general course is predictable, though it's hard to know what they will do or how strong they will get over longer periods.

→ Hurricanes
→ Cyclones
→ Typhoons

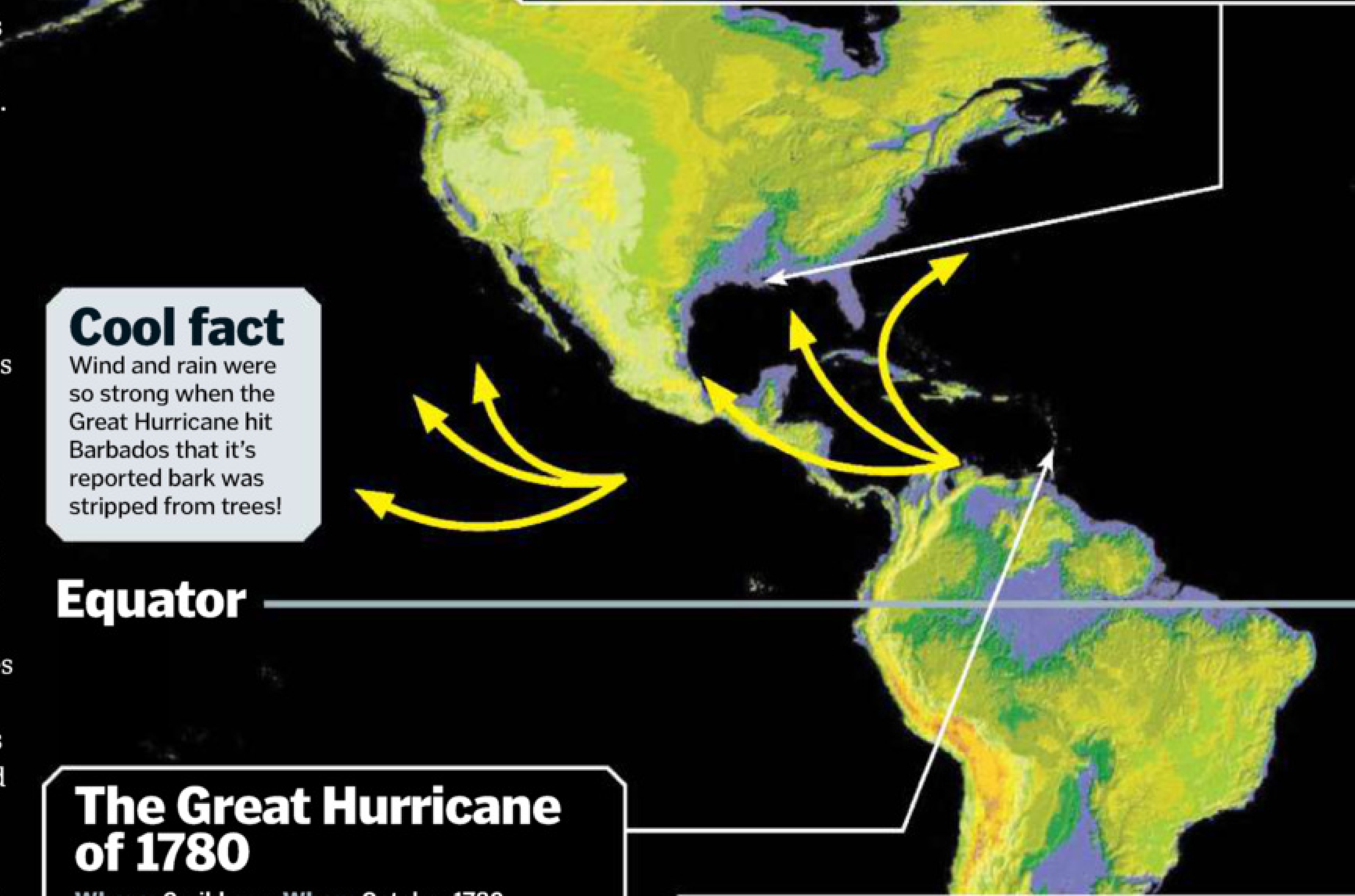
Hurricane Katrina

Where: New Orleans, USA **When:** August 2005
Fatalities: 1,833 **Damage:** $108bn (£670m)

One of the deadliest hurricanes in recent memory and the most destructive in US history, Hurricane Katrina profoundly affected New Orleans and its surroundings, where water reached up to 20 kilometres (12 miles) from the shore. Hurricane Katrina was the child of a waning tropical depression and an atmospheric trough known as a tropical wave. It moved across the Gulf of Mexico and rapidly strengthened over unseasonably warm waters, transforming into a maximum-rated category 5 hurricane and shifting away from Florida shortly before it slammed into the vulnerable city of New Orleans in south-east Louisiana.

Cool fact

Wind and rain were so strong when the Great Hurricane hit Barbados that it's reported bark was stripped from trees!



The Great Hurricane of 1780

Where: Caribbean **When:** October 1780
Fatalities: 22,000 **Damage:** Unknown

Simply known in English as the Great Hurricane of 1780, this category 5 beast is the deadliest hurricane on record. It predates when records officially began in 1851, so there's no exact data. It's likely though that its wind speed exceeded 320 kilometres (200 miles) per hour and it devastated the relatively unprepared parts of the Antilles in the Caribbean Sea. Casualties include fleets of British and French ships that were vying for control of the region as a part of the American Revolution. It's likely it formed in the eastern part of the Atlantic Ocean picking up strength as it approached Barbados.

Bhola Cyclone

Where: Bangladesh **When:** November 1970
Fatalities: 500,000 **Damage:** $490m (£306m)

The Bhola Cyclone was, meteorologically speaking, far from record-breaking. Its winds of around 140 kilometres (87 miles) per hour made it the equivalent of a relatively modest category 3 or 4 hurricane. But it struck a very vulnerable low-lying area of eastern Pakistan with a six-metre (20-foot) storm surge at night. With no way of warning locals, the authorities were helpless as hundreds of thousands drowned. Bhola formed from the remnants of a tropical storm and another depression in the Bay of Bengal, intensifying over four days and sweeping north into what is now Bangladesh.

Hurricane Vince

Where: Portugal/Spain **When:** October 2005
Fatalities: 0 **Damage:** N/A

Its winds peaked at 120 kilometres (75 miles) per hour, which only just registers as an official hurricane, it caused no damage and there were no fatalities, so why could Hurricane Vince be considered 'extreme'? Because of its unheard-of Spanish location and because of conditions at the time, which should never have produced a hurricane. The reasons for its formation near Madeira still aren't understood. The 22-degree-Celsius (72-degree-Fahrenheit) seas should never have allowed the 25-kilometre (15-mile) eye to form within the tropical storm. But form it did, and it lasted several hours, breaking up just before it hit the Spanish mainland.

Cool fact

Hurricane Vince proved to be a blessing in disguise, dropping several inches of rain on a drought-ridden Spain.

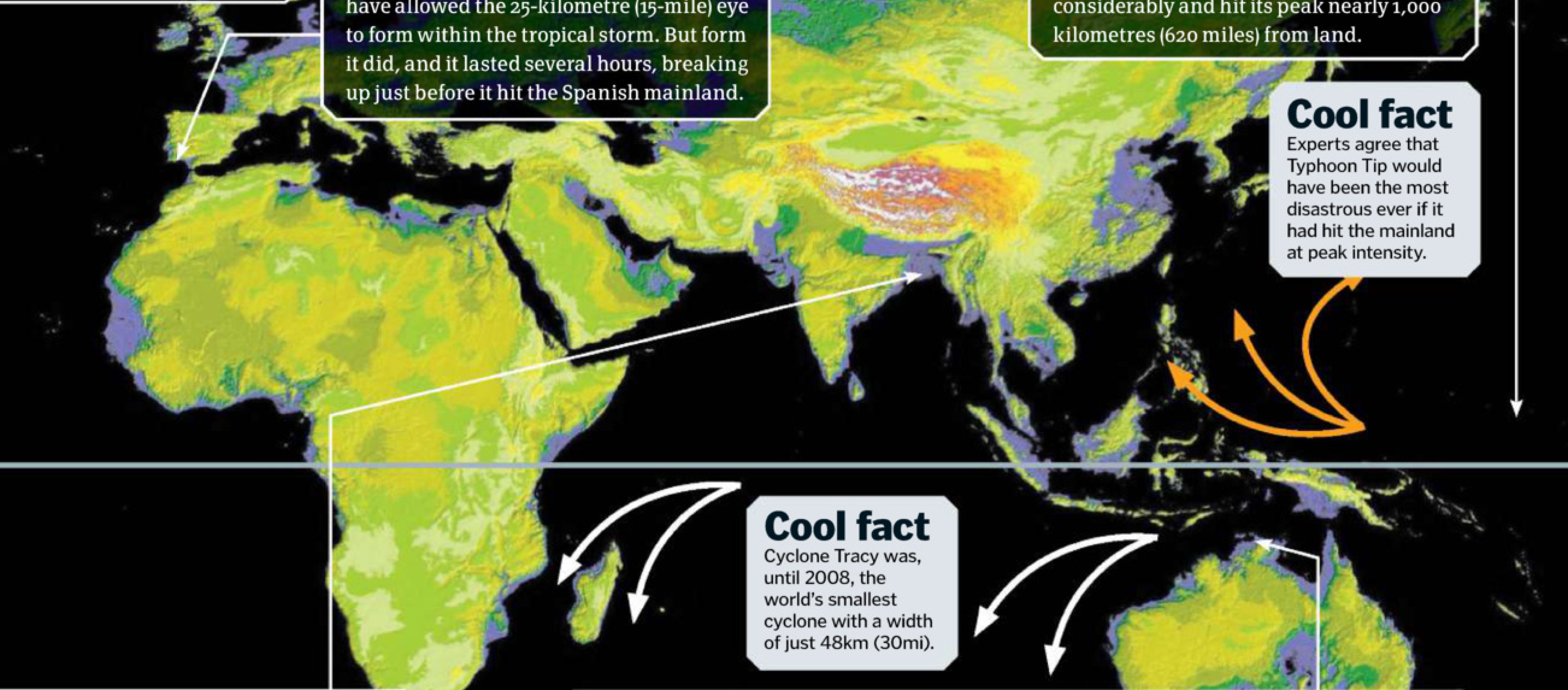
Super Typhoon Tip

Where: Eastern Pacific **When:** October 1979
Fatalities: 86 **Damage:** Unknown

Super Typhoon Tip was a monster, even for a typhoon. It broke several records: it had a diameter of 2,220 kilometres (1,380 miles) – nearly twice that of the previous record holder. It had sustained winds of 260 kilometres (160 miles) per hour and also set the world record for intensity with a staggering pressure low of 870 millibars. Typhoon Tip originated south of Micronesia though it remained a tropical storm until it made a sudden westerly diversion from Guam, where it intensified considerably and hit its peak nearly 1,000 kilometres (620 miles) from land.

Cool fact

Experts agree that Typhoon Tip would have been the most disastrous ever if it had hit the mainland at peak intensity.



Cool fact

Cyclone Tracy was, until 2008, the world's smallest cyclone with a width of just 48km (30mi).

Cyclone Tracy

Where: Darwin, Australia **When:** 25 December 1974 **Fatalities:** 71 **Damage:** $586m (£366m)

On Christmas Day 1974, a category 4 cyclone swept through Darwin, Australia, with winds gusting in excess of 217 kilometres (135 miles) per hour towing a four-metre (13-foot) storm surge. Locals had been warned, but partly due to the season and partly because Cyclone Selma had failed to make landfall earlier that month, many made no preparations at all. Cyclone Tracy developed in the seas 500 kilometres (300 miles) north of Australia and spent the next few days tracking south-east until it hit the warm water of the Timor Sea, where it intensified dramatically.

© Corbis; NASA

50 strange facts about weather

We answer your burning questions about the incredible variety and awesome power of the planet's most intriguing climatic phenomena

We like to be able to control everything, but weather – those changes in the Earth's atmosphere that spell out rain, snow, wind, heat, cold and more – is one of those things that is just beyond our power. Maybe that's why a cloudless sunny day or a spectacular display of lightning both have the ability to delight us. Meteorologists have come a long way in their capability to predict weather patterns, track changes and forecast what we can expect to see when we leave our homes each day. But they're not always right. It's not their fault; we still don't completely understand all of the processes that contribute to changes in the weather.

Here's what we do know: all weather starts with contrasts in air temperature and moisture in the atmosphere. Seems simple, right? Not exactly. Temperature and moisture vary greatly depending on a huge number of factors, like the Earth's rotation, where you're located, the angle at which the Sun is hitting it at any given time, your elevation, and your proximity to the ocean. These all lead to changes in atmospheric pressure. The atmosphere is chaotic, meaning that a very small, local change can have a far-reaching effect on much larger weather systems. That's why it's especially tough to make accurate forecasts more than a few days in advance.

DID YOU KNOW? *Many types of animals are reported to have fallen from the sky including frogs, worms and fish*

Is there a way to tell how close a storm is?

Lightning and thunder always go together, because thunder is the sound that results from lightning. Lightning bolts are close to 30,000 degrees Celsius (54,000 degrees Fahrenheit), so the air in the atmosphere that they zip through becomes superheated and quickly expands. That sound of expansion is called thunder, and on average it's about 120 decibels (a chainsaw is 125, for reference). Sometimes you can see lightning but not hear the thunder, but that's only because the lightning is too far away for you to hear it. Because light travels faster than sound, you always see lightning before hearing it.

1. Start the count
When you see a flash of lightning, start counting. A stopwatch would be the most accurate way.

2. Five seconds
The rule is that for every five seconds, the storm is roughly 1.6 kilometres (one mile) away.

3. Do the maths
Stop counting after the thunder and do the maths. If the storm's close, take the necessary precautions.

Is it possible to stop a hurricane?

We can't control the weather… or can we? Some scientists are trying to influence the weather through cloud seeding, or altering the clouds' processes by introducing chemicals like solid carbon dioxide (aka dry ice), calcium chloride and silver iodide. It has been used to induce rainfall during times of drought as well as to prevent storms.

What is the fastest wind ever recorded, not in a tornado?

407km/h (253mph)
Gusts recorded during Cyclone Olivia in 1996

CAN IT REALLY RAIN ANIMALS?

Animals have fallen from the sky before, but it's not actually 'raining' them. More likely strong winds have picked up large numbers of critters from ponds or other concentrations – perhaps from tornadoes or downspouts – then moved and deposited them. Usually the animals in question are small and live in or around water for a reason.

DOES FREAK WEATHER CONFUSE WILDLIFE?

A short period of unseasonable weather isn't confusing, but a longer one can be. For example, warm weather in winter may make plants bloom too early or animals begin mating long before spring actually rolls around.

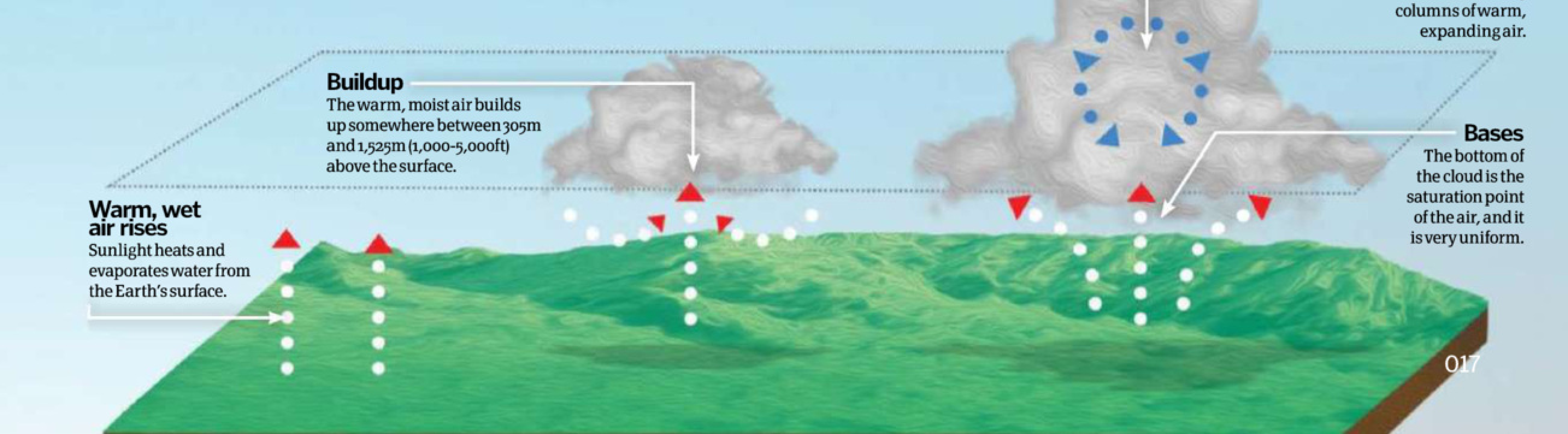
IS THE 'RED SKY AT NIGHT, SHEPHERD'S DELIGHT' SAYING TRUE?

The rest of the proverb is, 'Red sky at morning, shepherd's warning'. A red sky means you could see the red wavelength of sunlight reflecting off clouds. At sunrise, it was supposed to mean the clouds were coming towards you so rain might be on the way. If you saw these clouds at sunset, the risk had already passed. Which is 'good' or 'bad' is a matter of opinion.

WHAT ARE SNOW DOUGHNUTS?

Snow doughnuts, or rollers, are a rare natural phenomenon. If snow falls in a clump, gravity can pull it down over itself as it rolls. Normally it would collapse, but sometimes a hole forms. Wind and temperature also play key roles.

What makes clouds?



Warm, wet air rises
Sunlight heats and evaporates water from the Earth's surface.

Buildup
The warm, moist air builds up somewhere between 305m and 1,525m (1,000-5,000ft) above the surface.

Cloud
Air currents rise up and become thermals – rising columns of warm, expanding air.

Bases
The bottom of the cloud is the saturation point of the air, and it is very uniform.

WHAT ARE KATABATIC WINDS?

From the Greek for 'going downhill', a katabatic wind is also known as a drainage wind. It carries dense air down from high elevations, such as mountain tops, down a slope thanks to gravity. This is a common occurrence in places like Antarctica's Polar Plateau, where incredibly cold air on top of the plateau sinks and flows down through the rugged landscape, picking up speed as it goes. The opposite of katabatic winds are called anabatic, which are winds that blow *up* a steep slope.

DOES IT EVER SNOW IN AFRICA?

Several countries in Africa see snow – indeed, there are ski resorts in Morocco and regular snowfall in Tunisia. Algeria and South Africa also experience snowfall on occasion. It once snowed in the Sahara, but it was gone within 30 minutes. There's even snowfall around the equator if you count the snow-topped peaks of mountains.

WHAT COLOUR IS LIGHTNING?

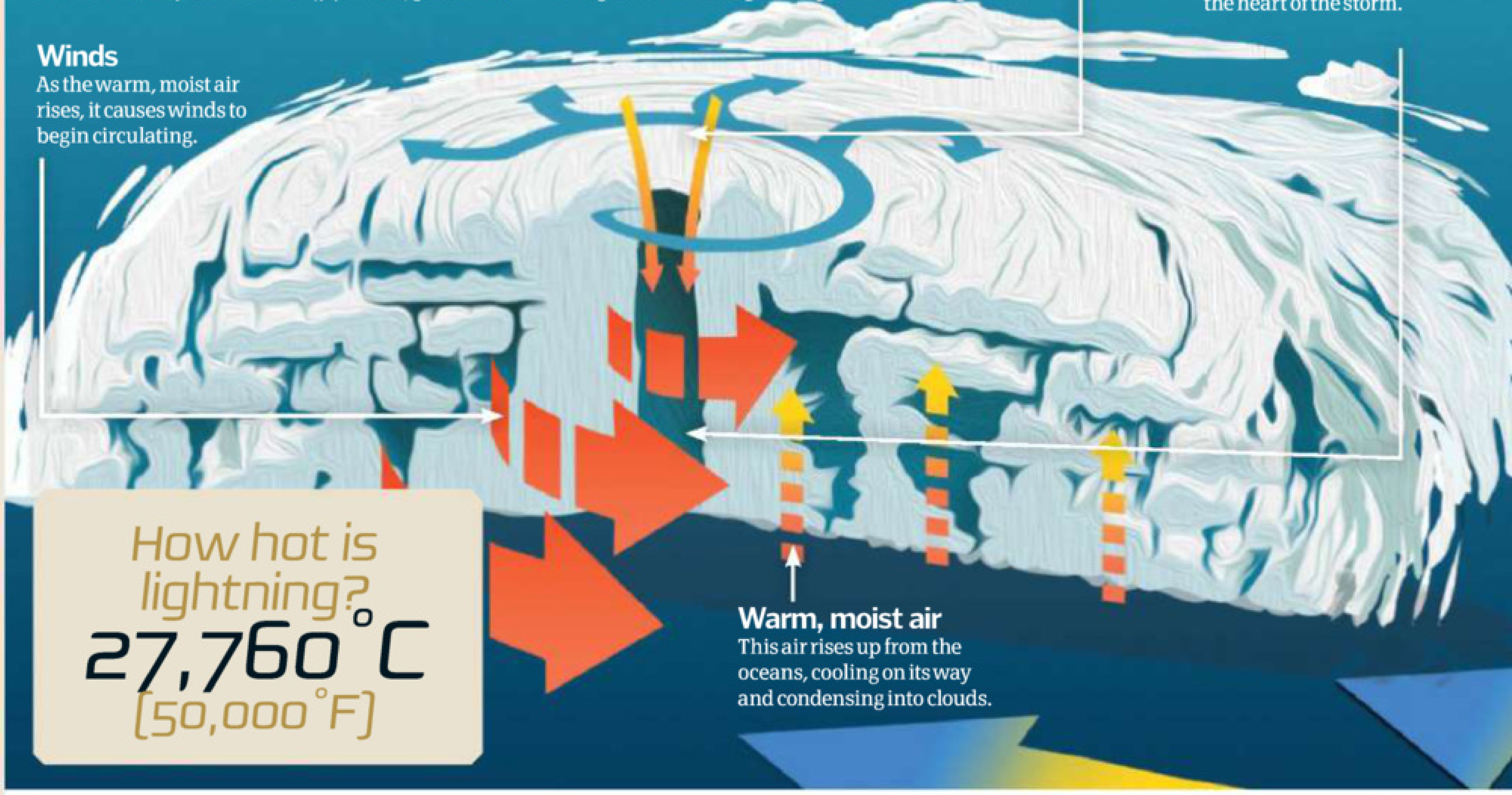
Usually lightning is white, but it can be every colour of the rainbow. There are a lot of factors that go into what shade the lightning will appear, including the amount of water vapour in the atmosphere, whether it's raining and the amount of pollution in the air. A high concentration of ozone, for example, can make lightning look blue.

WHY DO SOME CITIES HAVE THEIR OWN MICROCLIMATE?

Some large metropolises have microclimates – that is, their own small climates that differ from the local environment. Often these are due to the massive amounts of concrete, asphalt and steel; these materials retain and reflect heat and do not absorb water, which keeps a city warmer at night. This phenomenon specifically is often known as an urban heat island. The extreme energy usage in large cities may also contribute to this.

What causes hurricanes?

Depending on where they start, hurricanes may also be known as tropical cyclones or typhoons. They always form over oceans around the equator, fuelled by the warm, moist air. As that air rises and forms clouds, more warm, moist air moves into the area of lower pressure below. As the cycle continues, winds begin rotating and pick up speed. Once it hits 119 kilometres (74 miles) per hour, the storm is officially a hurricane. When hurricanes reach land, they weaken and die without the warm ocean air. Unfortunately they can move far inland, bringing a vast amount of rain and destructive winds. People sometimes cite 'the butterfly effect' in relation to hurricanes. This simply means something as small as the beat of a butterfly's wing can cause big changes in the long term.



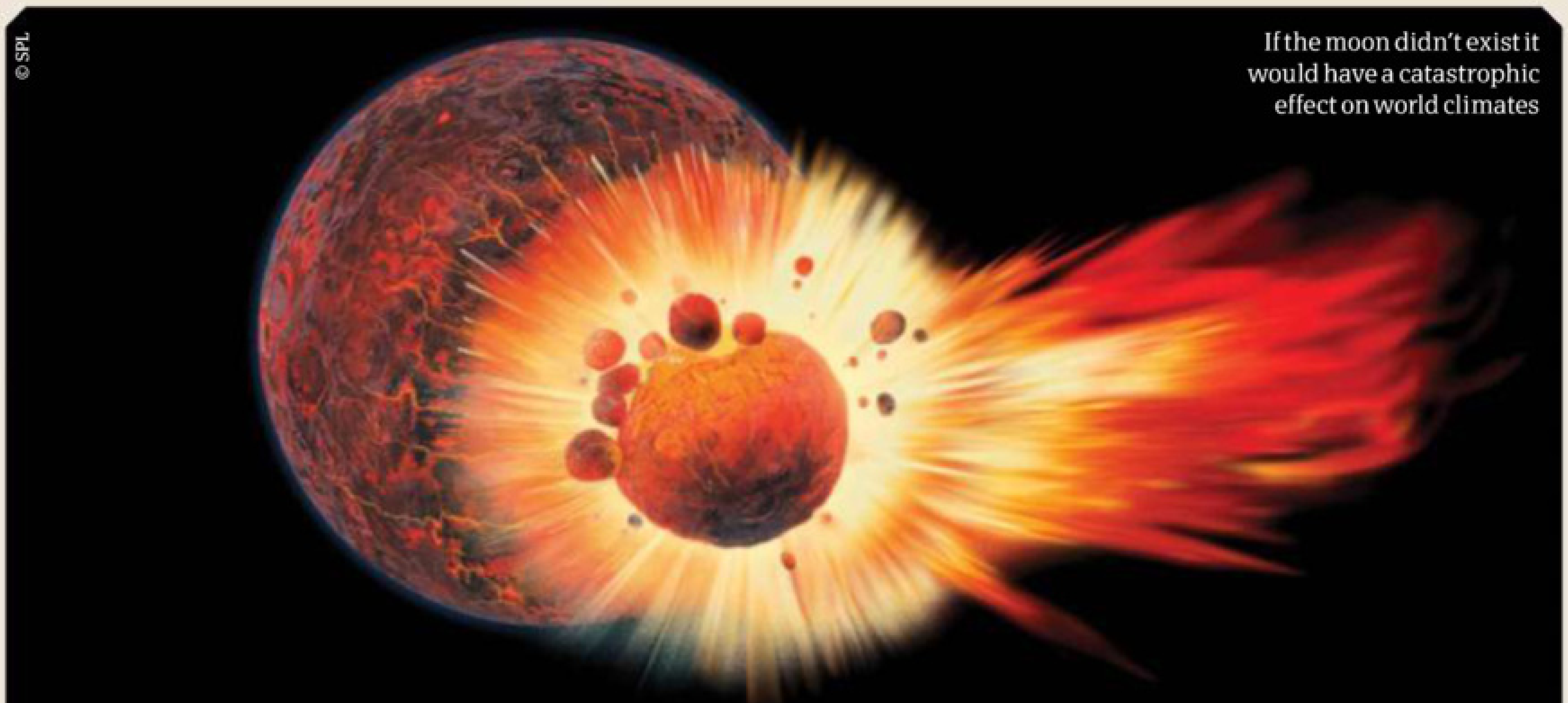
Cool, dry air
Cooled, dry air at the top of the system is sucked down in the centre, strengthening the winds.

Eye
High-pressure air flows downward through this calm, low-pressure area at the heart of the storm.

Winds
As the warm, moist air rises, it causes winds to begin circulating.

Warm, moist air
This air rises up from the oceans, cooling on its way and condensing into clouds.

How hot is lightning?
27,760°C
(50,000°F)



© SPL

If the moon didn't exist it would have a catastrophic effect on world climates

What would happen to our weather without the moon?

It's difficult to know exactly what would happen to our weather if the moon were destroyed. The moon powers Earth's tides, which in turn influence our weather systems. In addition, the loss of the moon would affect the Earth's rotation – how it spins on its axis. The presence of the moon creates a sort of drag, so its loss would probably speed up the rotation, changing the length of day and night. In addition it would alter the tilt of the Earth too, which causes the changes in our seasons. Some places would be much colder while others would become much hotter. Let's not neglect the impact of the actual destruction, either; that much debris would block out the Sun and rain down on Earth, causing massive loss of life. Huge chunks that hit the ocean could cause great tidal waves, for instance.

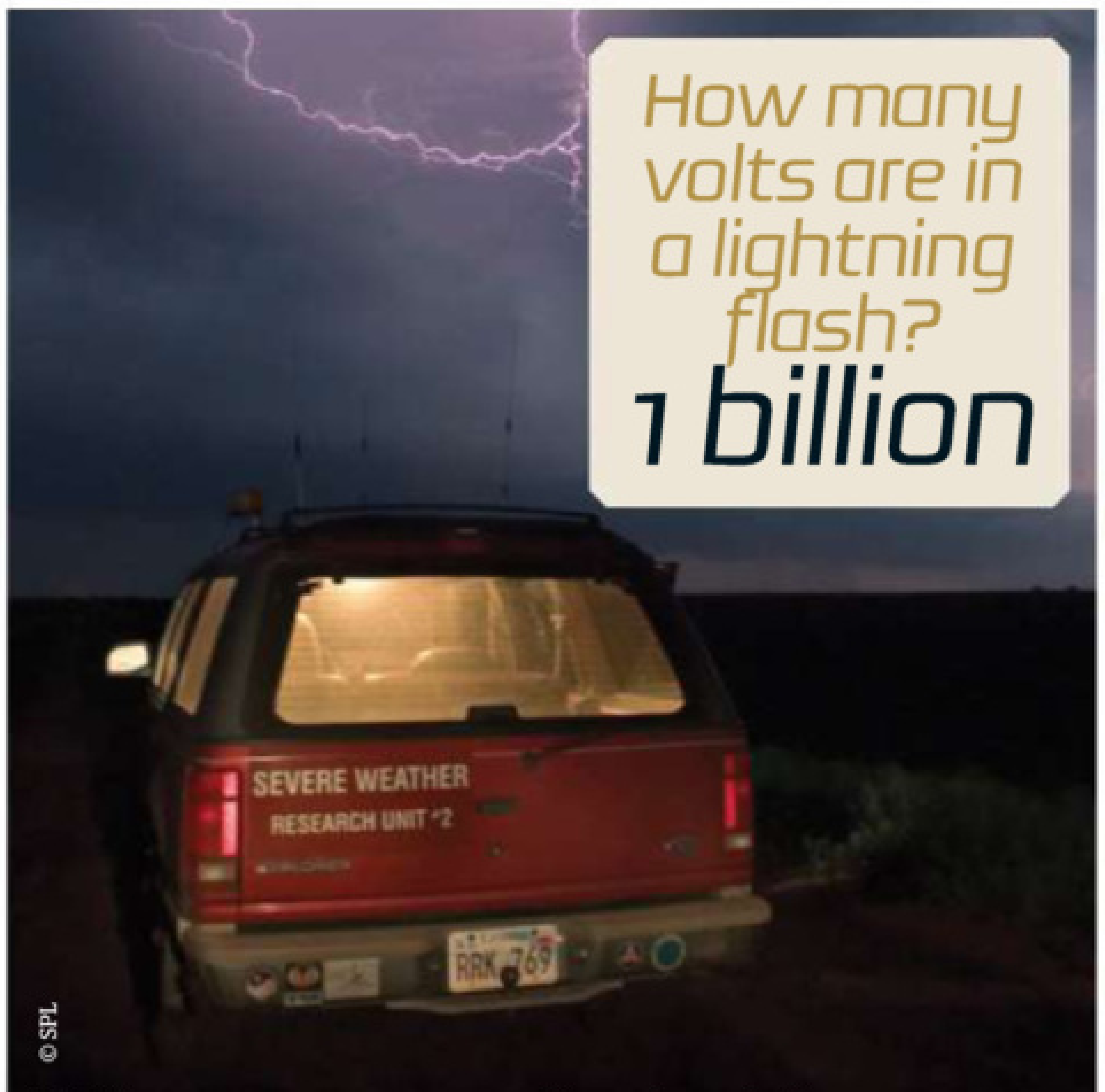
RECORD BREAKERS
KILLER FLOOD

3.7-4MN

DEADLIEST NATURAL DISASTER

The Huang He flood of 1931 covered over 100,000 square kilometres (62,000 square miles) around the Yellow River basin in China, claiming up to a staggering 4 million lives.

DID YOU KNOW? *Sir Francis Beaufort devised his wind scale by using the flags and sails of his ship as measuring devices*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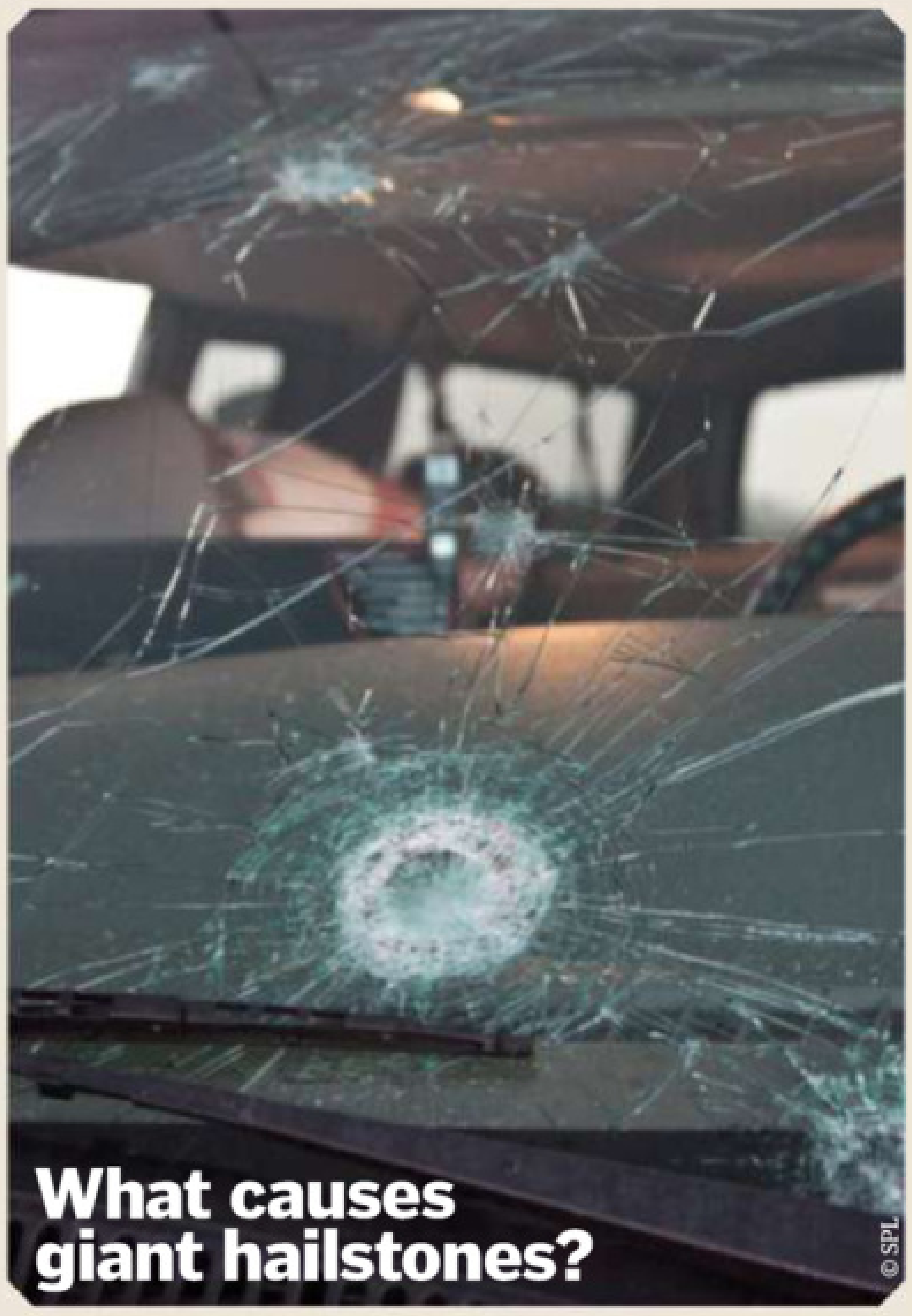
How many volts are in a lightning flash?

1 billion

Why are you safer inside a car during an electrical storm?

People used to think the rubber tyres on a car grounded any lightning that may strike it and that's what kept you safe. However, you're safer in your car during an electrical storm because of the metal frame. It serves as a conductor of electricity, and channels the lightning away into the ground without impacting anything – or anyone – inside; this is known as a Faraday cage. While it is potentially dangerous to use a corded phone or other appliances during a storm because lightning can travel along cables, mobile or cordless phones are fine. It's also best to avoid metallic objects, including golf clubs.


© SPL

What causes giant hailstones?

Put simply, giant hailstones come from giant storms – specifically a thunderstorm called a supercell. It has a strong updraft that forces wind upwards into the clouds, which keeps ice particles suspended for a long period. Within the storm are areas called growth regions; raindrops spending a long time in these are able to grow into much bigger hailstones than normal.

WHAT IS CLOUD IRIDESCENCE?

This happens when small droplets of water or ice crystals in clouds scatter light, appearing as a rainbow of colours. It's not a common phenomenon because the cloud has to be very thin, and even then the colours are often overshadowed by the Sun.

WHAT DO WEATHER SATELLITES DO?

The GOES (Geostationary Operational Environmental Satellite) system is run by the US National Environmental Satellite, Data, and Information Service (NESDIS). The major element of GOES comprises four different geosynchronous satellites (although there are other geo-satellites either with other uses now or decommissioned).

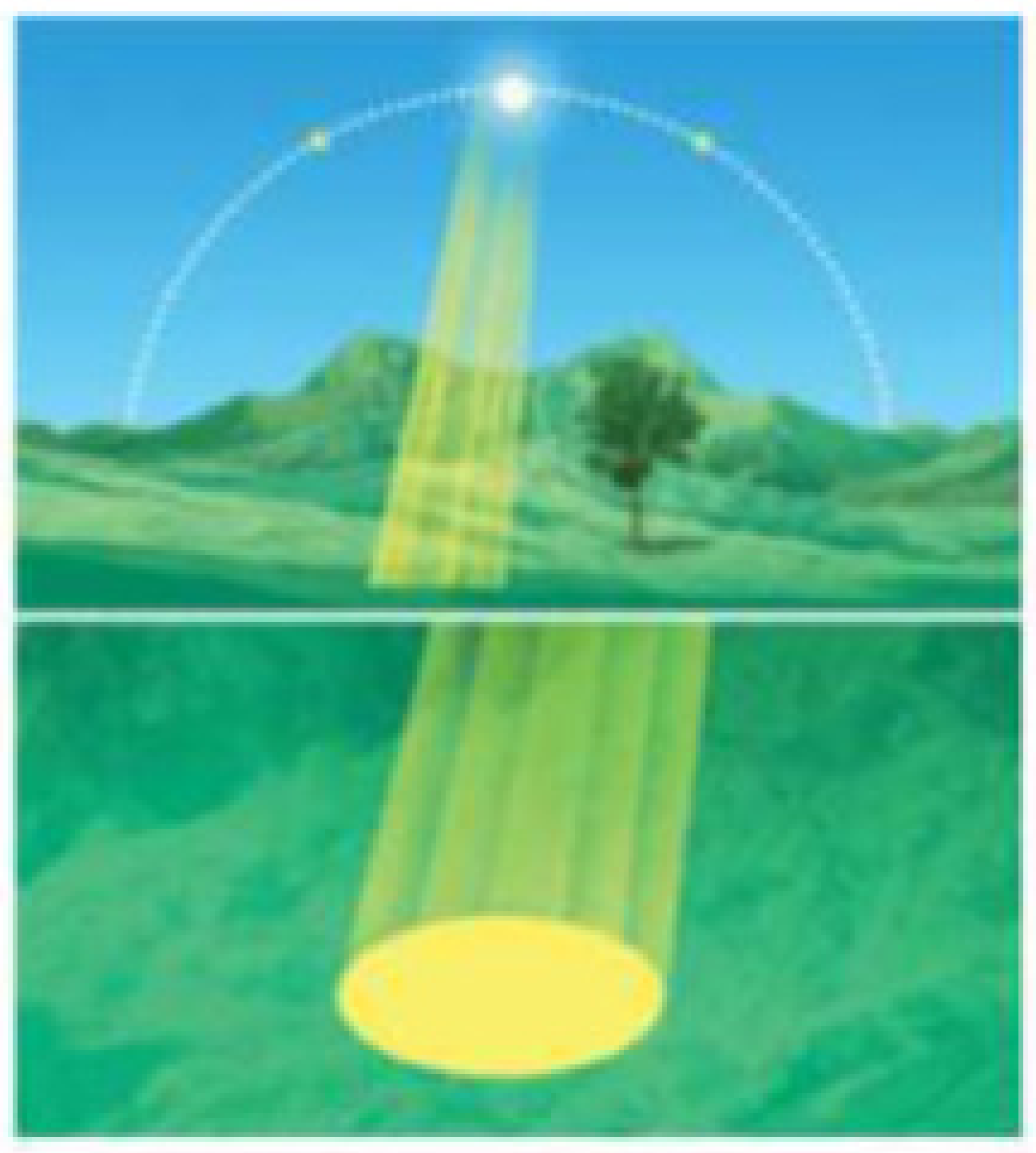
The whole system is used by NOAA's National Weather Service for forecasting, meteorological research and storm tracking. The satellites provide continuous views of Earth, giving data on air moisture, temperature and cloud cover. They also monitor solar and near-space activities like solar flares and geomagnetic storms.

How does the Sun cause the seasons?

Seasons are caused by the Earth's revolution around the Sun, as well as the tilt of the Earth on its axis. The hemisphere receiving the most direct sunlight experiences spring and summer, while the other experiences autumn and winter. During the warmer months, the Sun is higher in the sky, stays above the horizon for longer, and its rays are more direct. During the cooler half, the Sun's rays aren't as strong and it's lower in the sky. The tilt causes these dramatic differences, so while those in the northern hemisphere are wrapping up for snow, those in the southern hemisphere may be sunbathing on the beach.

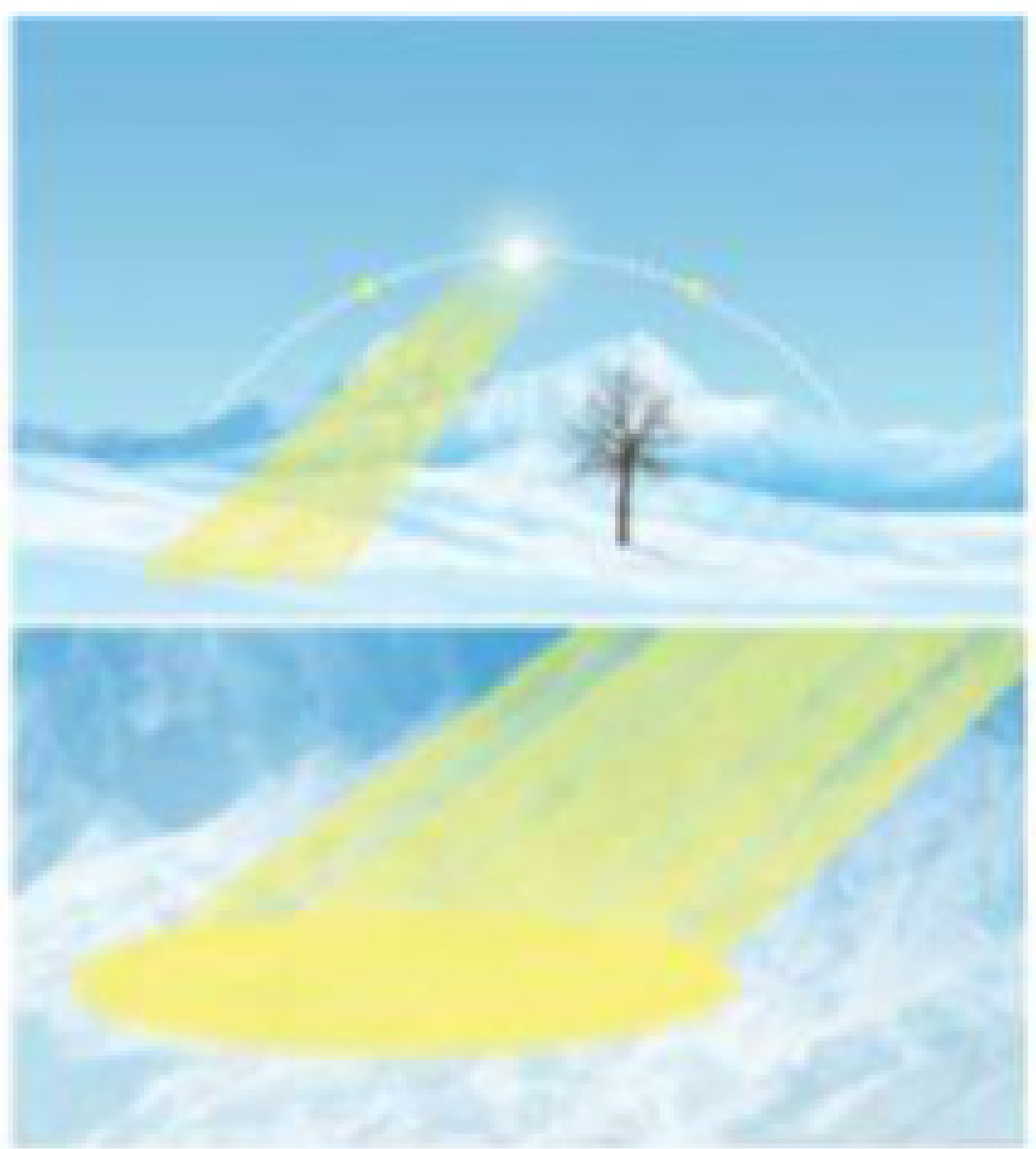
SUMMER

The Sun is at its highest point in the sky and takes up more of the horizon. Its rays are more direct.



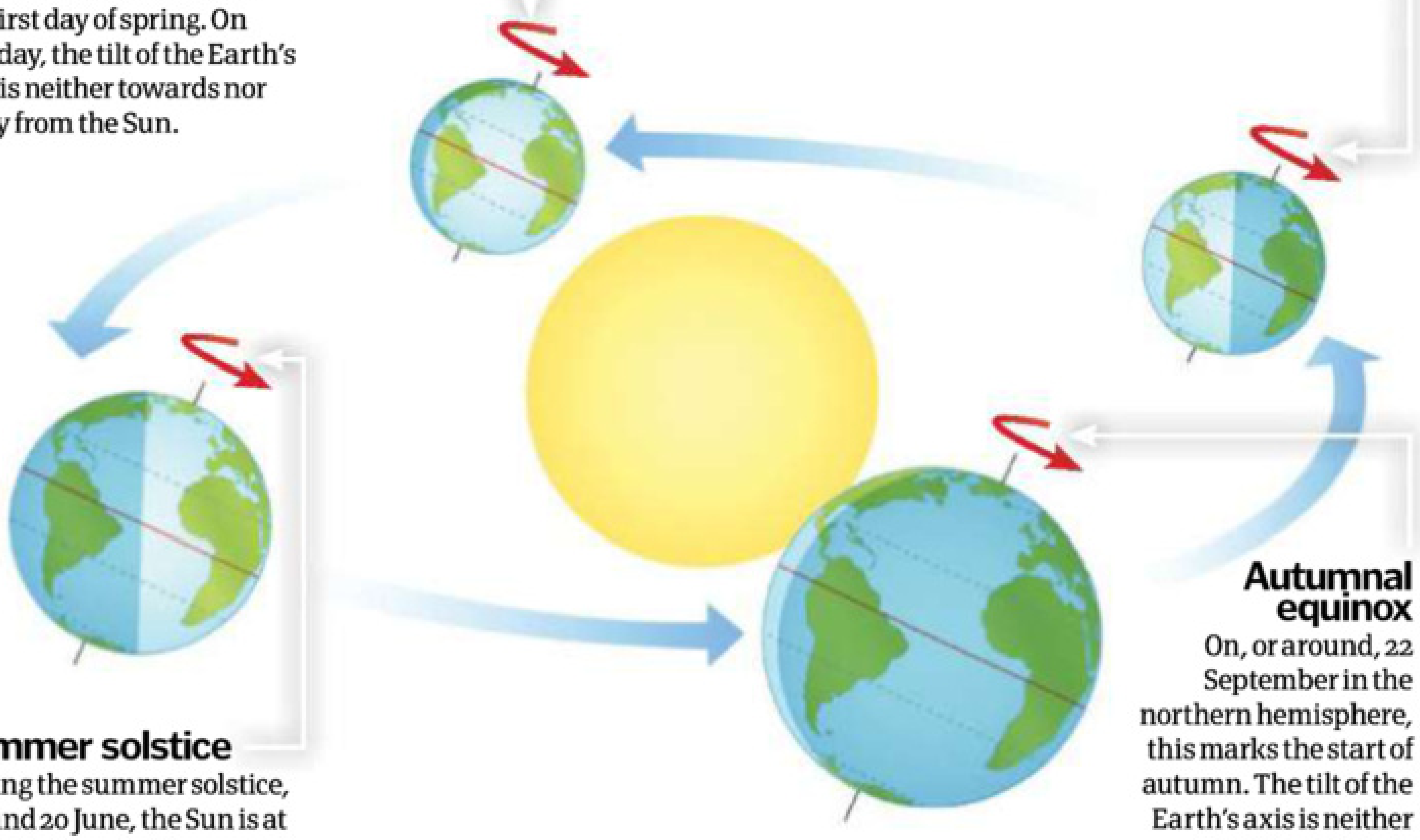
WINTER

The Sun is at its lowest point in the sky and there is less daylight. The rays are also more diffuse.



Vernal equinox
For the northern hemisphere, this day – around 20 March – marks the first day of spring. On this day, the tilt of the Earth's axis is neither towards nor away from the Sun.

Winter solstice
The winter solstice marks the beginning of winter, with the Sun at its lowest point in the sky; it takes place around 20 December each year.



Summer solstice
During the summer solstice, around 20 June, the Sun is at its highest, or northernmost, point in the sky.

Autumnal equinox
On, or around, 22 September in the northern hemisphere, this marks the start of autumn. The tilt of the Earth's axis is neither towards nor away from the Sun.

HOW LONG DOES A RAINBOW LAST?

There is no set rule for the duration a rainbow will last. It all depends on how long the light is refracted by water droplets in the air (eg rain, or the spray from a waterfall). It can range from moments to much longer.

WHY DOES IT SMELL FUNNY AFTER RAIN?

This scent comes from bacteria in the soil. Once the earth dries, the bacteria (called actinomycetes) release spores. Rainfall kicks these spores up into the air, and then the moist air disperses them. They tend to have a sweet, earthy odour.

HOW MUCH RAIN CAN A HURRICANE BRING?

The average hurricane, with a radius of about 1,330 kilometres (825 miles), can dump as much as 21.3×10^{15} cubic centimetres (1.3×10^{15} cubic inches) of water a day. That's enough rain to fill up 22 million Olympic-size swimming pools!

HOW DO DROUGHTS AND HEAT WAVES DIFFER?

Droughts are about an extreme lack of water, usually due to lower than average rainfall, and last for months or even years. There's no set definition of a heat wave, but it typically means higher than average temperatures for several consecutive days. Both can lead to crop failures and fatalities.

WHY ARE RAINBOWS ARCH-SHAPED?

Rainbows are arched due to the way sunlight hits raindrops. It bends as it passes through because it slows during this process. Then, as the light passes out of the drop, it bends again as it returns to its normal speed.

WHAT IS THE GREEN FLASH YOU SEE AS THE SUN SETS SOMETIMES?

At sunsets (or indeed rises), the Sun can occasionally change colour due to refraction. This can cause a phenomenon called green flash. It only lasts for a second or two so can be very tricky to spot.

What's the difference between rain, sleet and snow?

When it comes to precipitation, it's all about temperature. When the air is sufficiently saturated, water vapour begins to form clouds around ice, salt or other cloud seeds. If saturation continues, water droplets grow and merge until they become heavy enough to fall as rain. Snow forms when the air is cold enough to freeze supercooled water droplets – lower than -31 degrees Celsius (-34 degrees Fahrenheit) – then falls. Sleet is somewhere in between: it starts as snow but passes through a layer of warmer air before hitting the ground, resulting in some snow melting.

What is the eye of a storm?

The eye is the calm centre of a storm like a hurricane or tornado, without any weather phenomena. Because these systems consist of circular, rotating winds, air is funnelled downward through the eye and feeds back into the storm itself.

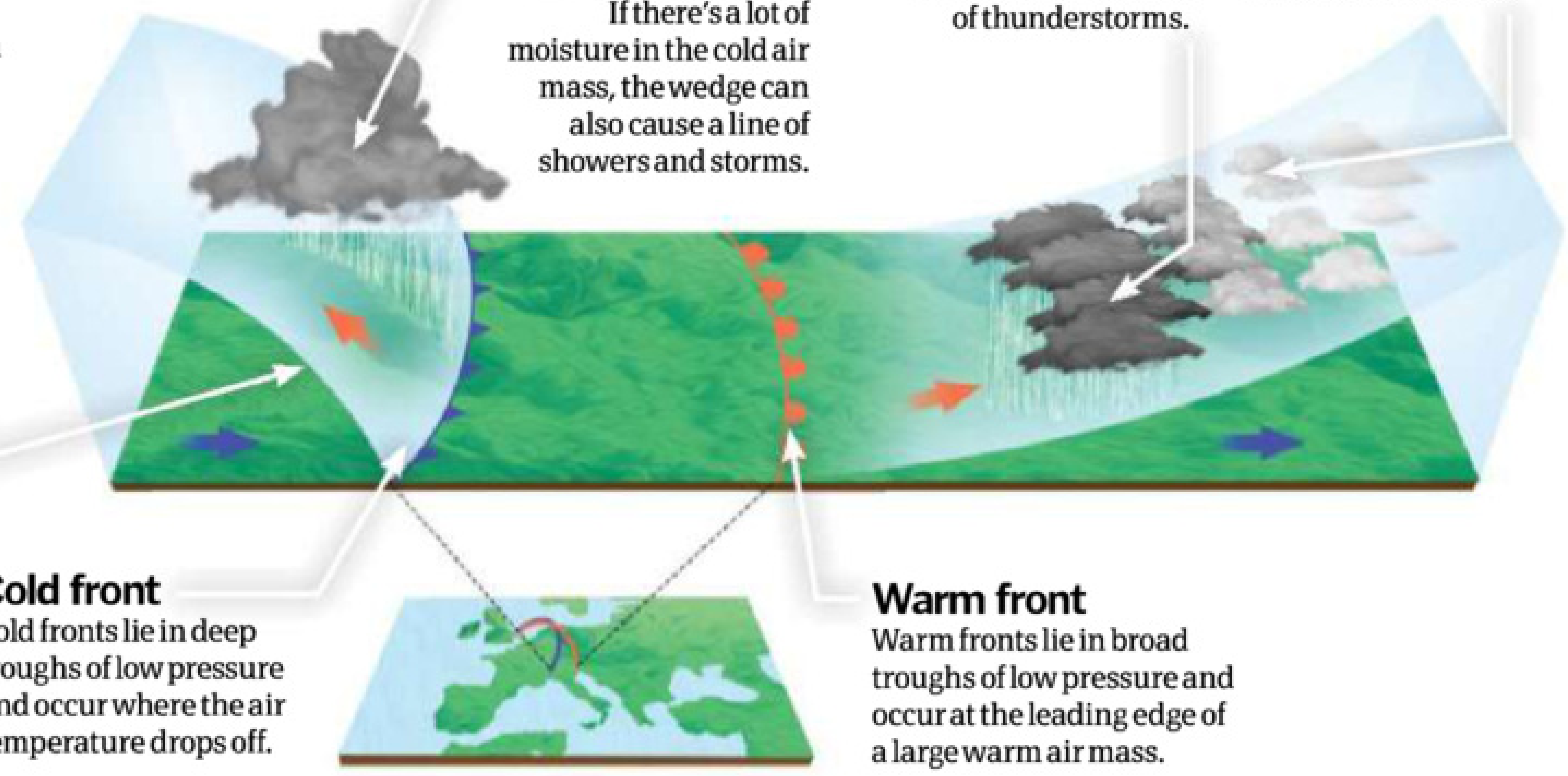
How high is a typical cloud?
2,000m
(6,550ft)

The eye at the centre of a hurricane tends to be 20-50km (12-31mi) in diameter

© NASA

What is a weather front?

A weather front is the separation between two different masses of air, which have differing densities, temperature and humidity. On weather maps, they're delineated by lines and symbols. The meeting of different frontal systems causes the vast majority of weather phenomena.



Wet 'n' wild
If there's a lot of moisture in the cold air mass, the wedge can also cause a line of showers and storms.

Thunderstorms
Unstable masses of warm air often contain stratiform clouds, full of thunderstorms.

Fog
Fog often comes before the slow-moving warm front.

Wedge
As cold air is denser, it often 'wedges' beneath the warm air. This lift can cause wind gusts.

Cold front
Cold fronts lie in deep troughs of low pressure and occur where the air temperature drops off.

Warm front
Warm fronts lie in broad troughs of low pressure and occur at the leading edge of a large warm air mass.

STRANGE BUT TRUE
CLOUD LIGHTING

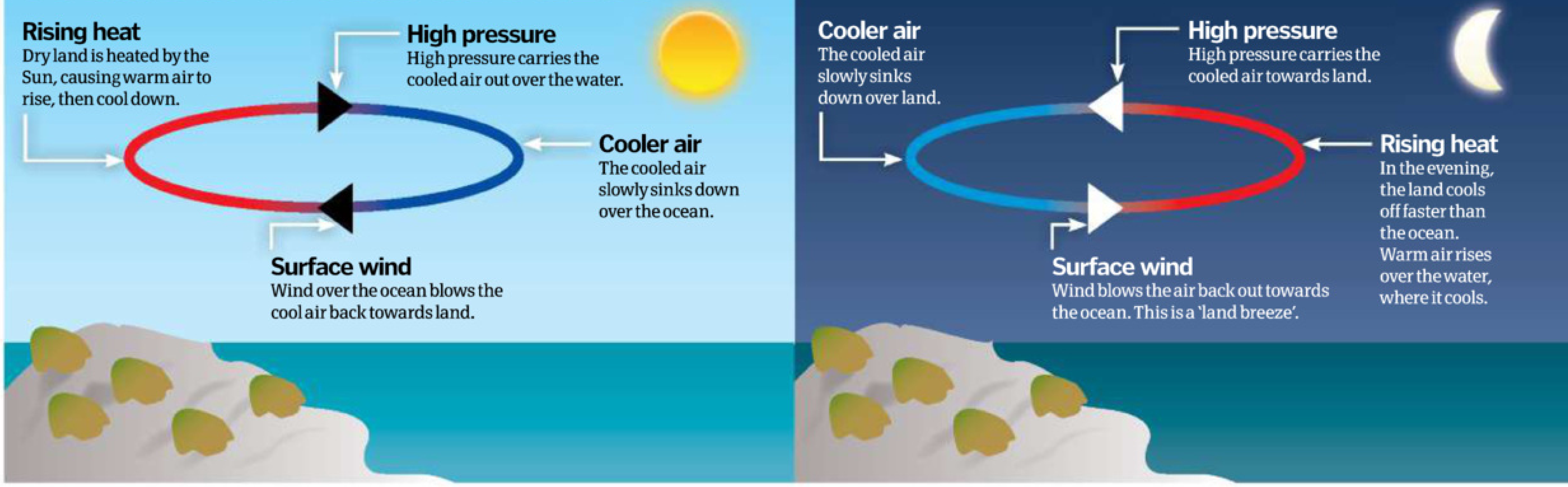
DAY AT NIGHT

Noctilucent clouds occur when icy polar mesospheric clouds – the highest clouds in the Earth's atmosphere at 76-85 kilometres (47-53 miles) – refract the fading twilight after the Sun has set, temporarily illuminating the sky.

© Martin Koitmäe

DID YOU KNOW? *Fog is made up of millions of droplets of water floating in the air*

What is a sea breeze?



Rising heat
Dry land is heated by the Sun, causing warm air to rise, then cool down.

High pressure
High pressure carries the cooled air out over the water.

Cooler air
The cooled air slowly sinks down over the ocean.

Surface wind
Wind over the ocean blows the cool air back towards land.

Cooler air
The cooled air slowly sinks down over land.

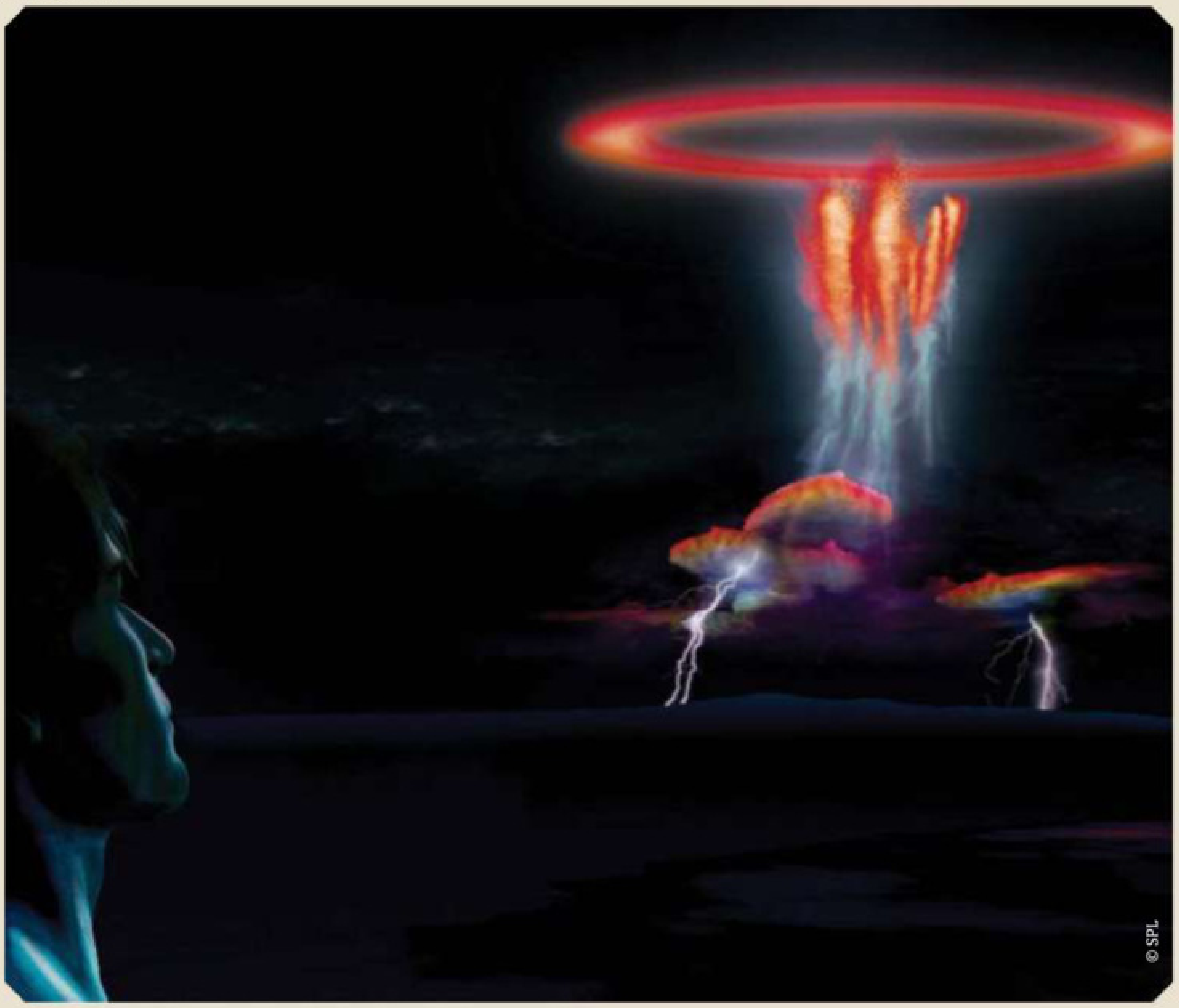
High pressure
High pressure carries the cooled air towards land.

Rising heat
In the evening, the land cools off faster than the ocean. Warm air rises over the water, where it cools.

Surface wind
Wind blows the air back out towards the ocean. This is a 'land breeze'.

What are red sprites and blue jets?

These are both atmospheric and electrical phenomena that take place in the upper atmosphere, and are also known as upper-atmosphere discharge. They take place above normal lightning; blue jets occur around 40-50 kilometres (25-30 miles) above the Earth, while red sprites are higher at 50-100 kilometres (32-64 miles). Blue jets happen in cone shapes above thunderstorm clouds, and are not related to lightning. They're blue due to ionised emissions from nitrogen. Red sprites can appear as different shapes and have hanging tendrils. They occur when positive lightning goes from the cloud to the ground.



© SPL

Does lightning ever strike in the same place twice?

Yes, lightning often strikes twice in the same location. If there's a thunderstorm and lightning strikes, it's just as likely to happen again. Many tall structures get struck repeatedly during thunderstorms, such as New York City's famed Empire State Building or NASA's shuttle launch pad in Cape Canaveral, Florida.

How cold was the coldest day in history?

-89°C (-129°F)

Recorded on 21 July 1983 at Vostok II Station, Antarctica

Why does the Sun shine?

The Sun is a super-dense ball of gas, where hydrogen is continually burned into helium (nuclear fusion). This generates a huge deal of energy, and the core reaches 15 million degrees Celsius (27 million degrees Fahrenheit). This extreme heat produces lots of light.

WHAT IS CLOUD IRIDESCENCE?

This happens when small droplets of water or ice crystals in clouds scatter light, appearing as a rainbow of colours. It's not common because the cloud has to be very thin, and the colours are often overshadowed by the Sun.

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WHY ARE CLOUDS FLUFFY?

Fluffy-looking clouds are a type called cumulus. They form when warm air rises from the ground, meets a layer of cool air and moisture condenses. If the cloud grows enough to meet an upper layer of freezing air, rain or snow may fall from the cloud.

WHAT'S IN ACID RAIN?

Acid rain is full of chemicals like nitrogen oxide, carbon dioxide and sulphur dioxide, which react with water in the rain. Much of it comes from coal powerplants, cars and factories. It can harm wildlife and damage buildings.

WHY CAN I SEE MY BREATH IF IT'S COLD?

Your breath is full of warm water vapour because your lungs are moist. When it's cold outside and you breathe out, that vapour cools rapidly as it hits the cold air. The water molecules slow down, begin to change form, and bunch up together, becoming visible.

Where are you most likely to get hit by lightning?

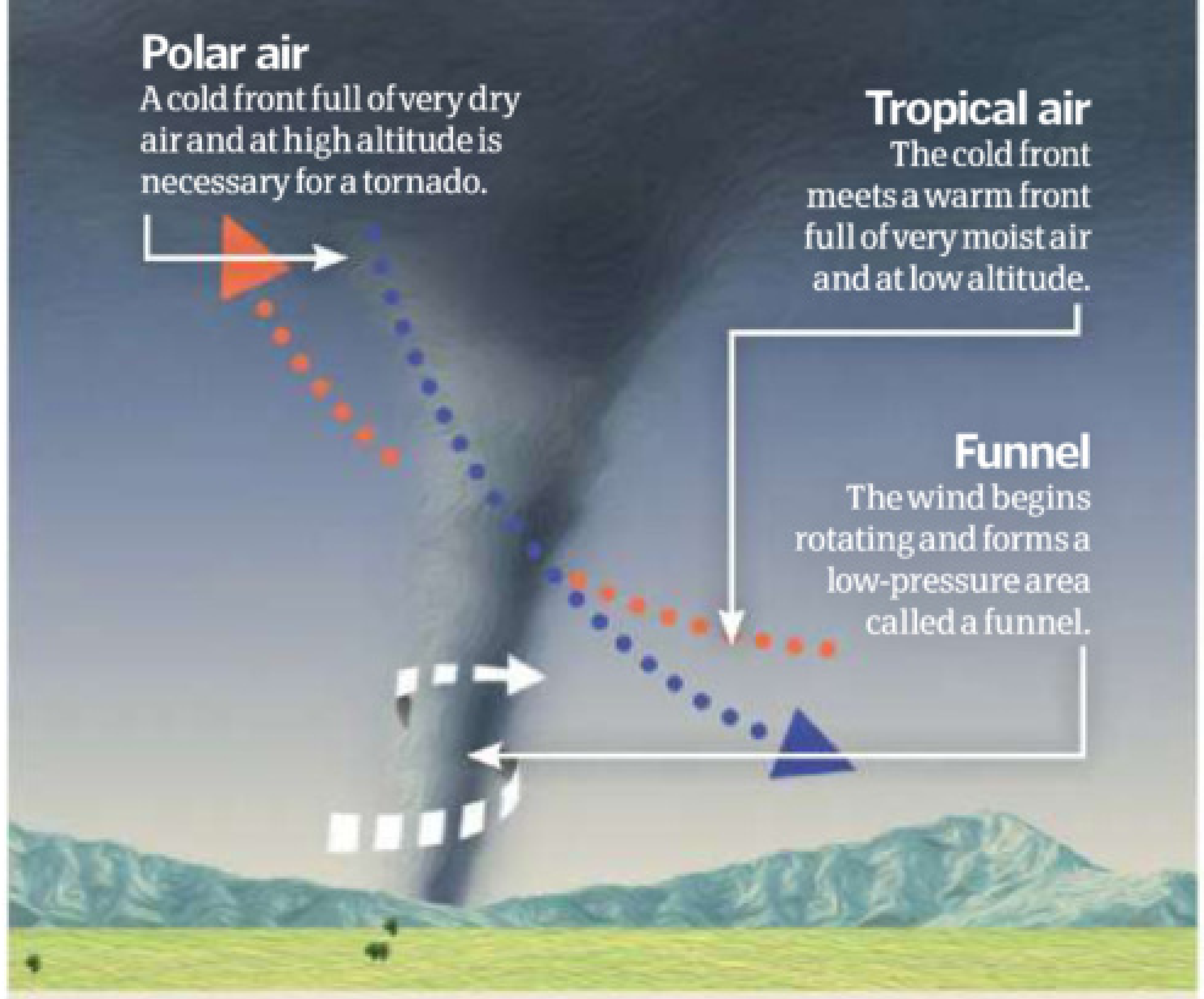
Generally lightning strikes occur most often during the summer. So the place where lightning strikes occur the most is a place where summer-like weather prevails year-round: Africa. Specifically, it's the village of Kifuka in the Democratic Republic of Congo. Each year, it gets more than 150 lightning strikes within one square kilometre. Roy Sullivan didn't live in Kifuka but he still managed to get struck by lightning seven separate times while working as a park ranger in the Shenandoah National Park in the USA. The state in which he lived – Virginia – does have a high incidence of lightning strikes per year, but since Sullivan spent his job outdoors in the mountains, his risk was greater due to his exposure.

How many thunderstorms break out worldwide at any given moment?

2,000

Lightning occurs most often in hot, summer-like climates

How do tornadoes work?


Polar air
A cold front full of very dry air and at high altitude is necessary for a tornado.
Tropical air
The cold front meets a warm front full of very moist air and at low altitude.
Funnel
The wind begins rotating and forms a low-pressure area called a funnel.

Tornadoes start out with severe thunderstorms called supercells. They form when polar air comes in contact with tropical air in a very unstable atmosphere. Supercells contain a rotating updraft of air that is known as a mesocyclone, which keeps them going for a long time. High winds add to the rotation, which keeps getting faster and faster until eventually it forms a funnel. The funnel cloud creates a sucking area of low pressure at the bottom. As soon as this funnel comes in to contact with the Earth, you have a tornado.

How hot is the Sun?

The core is around

15,000,000°C

(27,000,000°F)

Why is it so quiet after it snows?

It's peaceful after snowfall as the snow has a dampening effect; pockets of air between the flakes absorb noise. However, if it's compacted snow and windy, the snow might actually reflect sound.

How many lightning strikes are there each second globally?

100

How hot was the hottest day in history?

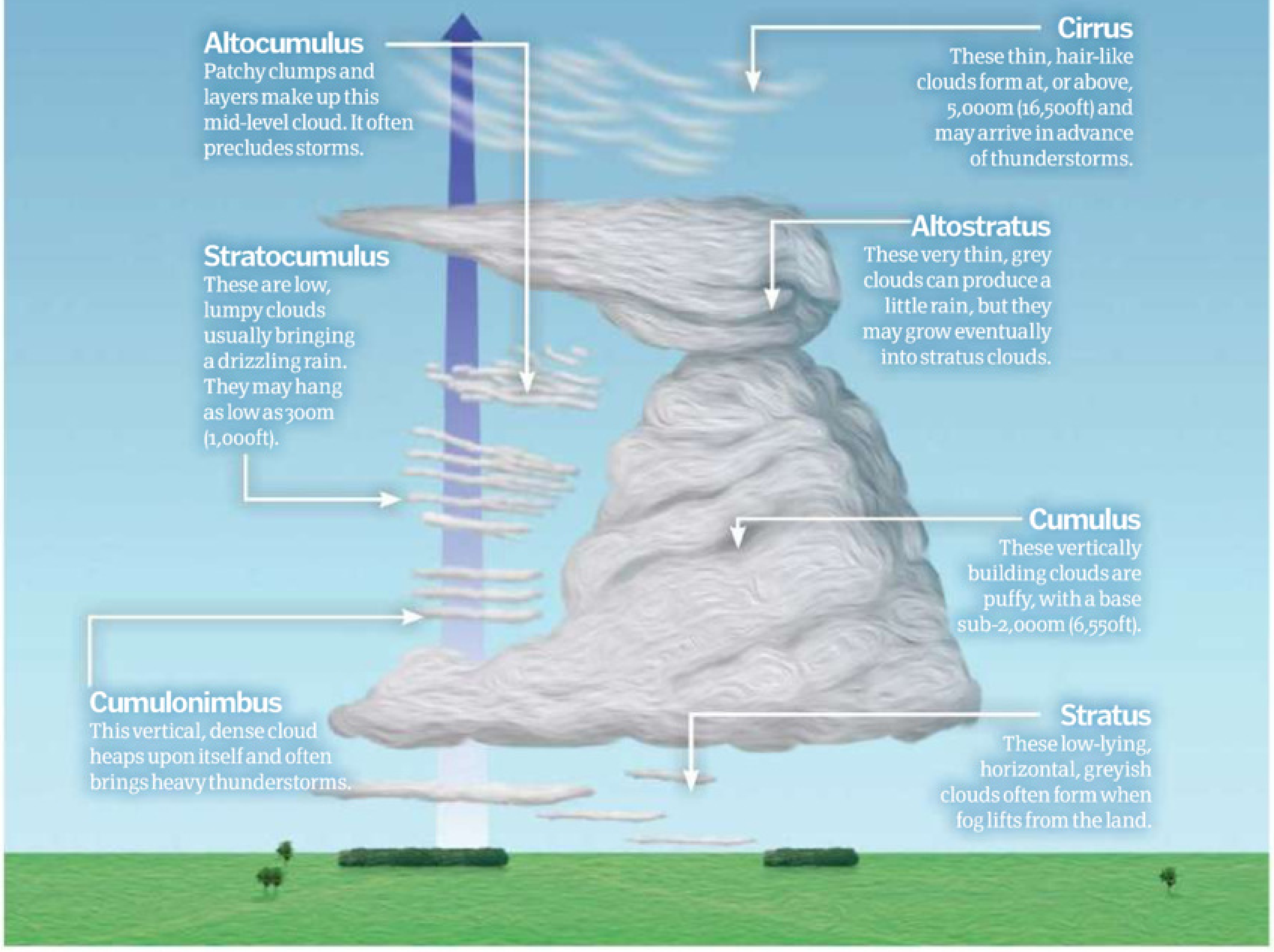
58°C (136°F)

Recorded on 13 September 1922 in Al Aziziyah, Libya

What is ball lightning?

This mysterious phenomenon looks like a glowing ball of lightning, and floats near the ground before disappearing, often leaving a sulphur smell. Despite many sightings, we're still not sure what causes it.

Why do clouds look different depending on their height?



Altocumulus Patchy clumps and layers make up this mid-level cloud. It often precludes storms.

Cirrus These thin, hair-like clouds form at, or above, 5,000m (16,500ft) and may arrive in advance of thunderstorms.

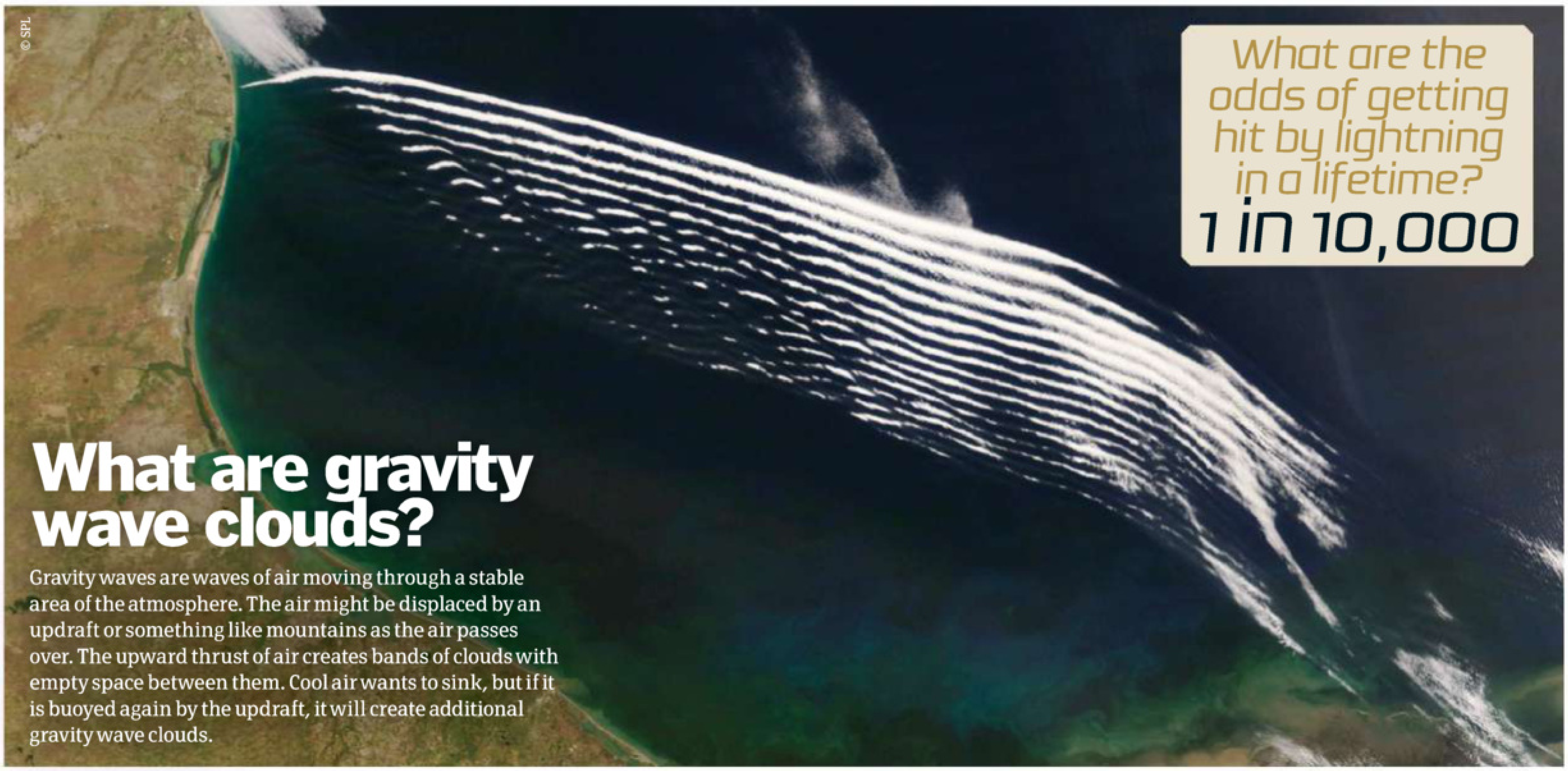
Stratocumulus These are low, lumpy clouds usually bringing a drizzling rain. They may hang as low as 300m (1,000ft).

Altostratus These very thin, grey clouds can produce a little rain, but they may grow eventually into stratus clouds.

Cumulus These vertically building clouds are puffy, with a base sub-2,000m (6,550ft).

Cumulonimbus This vertical, dense cloud heaps upon itself and often brings heavy thunderstorms.

Stratus These low-lying, horizontal, greyish clouds often form when fog lifts from the land.



© SPL

What are the odds of getting hit by lightning in a lifetime?

1 in 10,000

What are gravity wave clouds?

Gravity waves are waves of air moving through a stable area of the atmosphere. The air might be displaced by an updraft or something like mountains as the air passes over. The upward thrust of air creates bands of clouds with empty space between them. Cool air wants to sink, but if it is buoyed again by the updraft, it will create additional gravity wave clouds.

DEADLY WEATHER

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DEADLY WEATHER

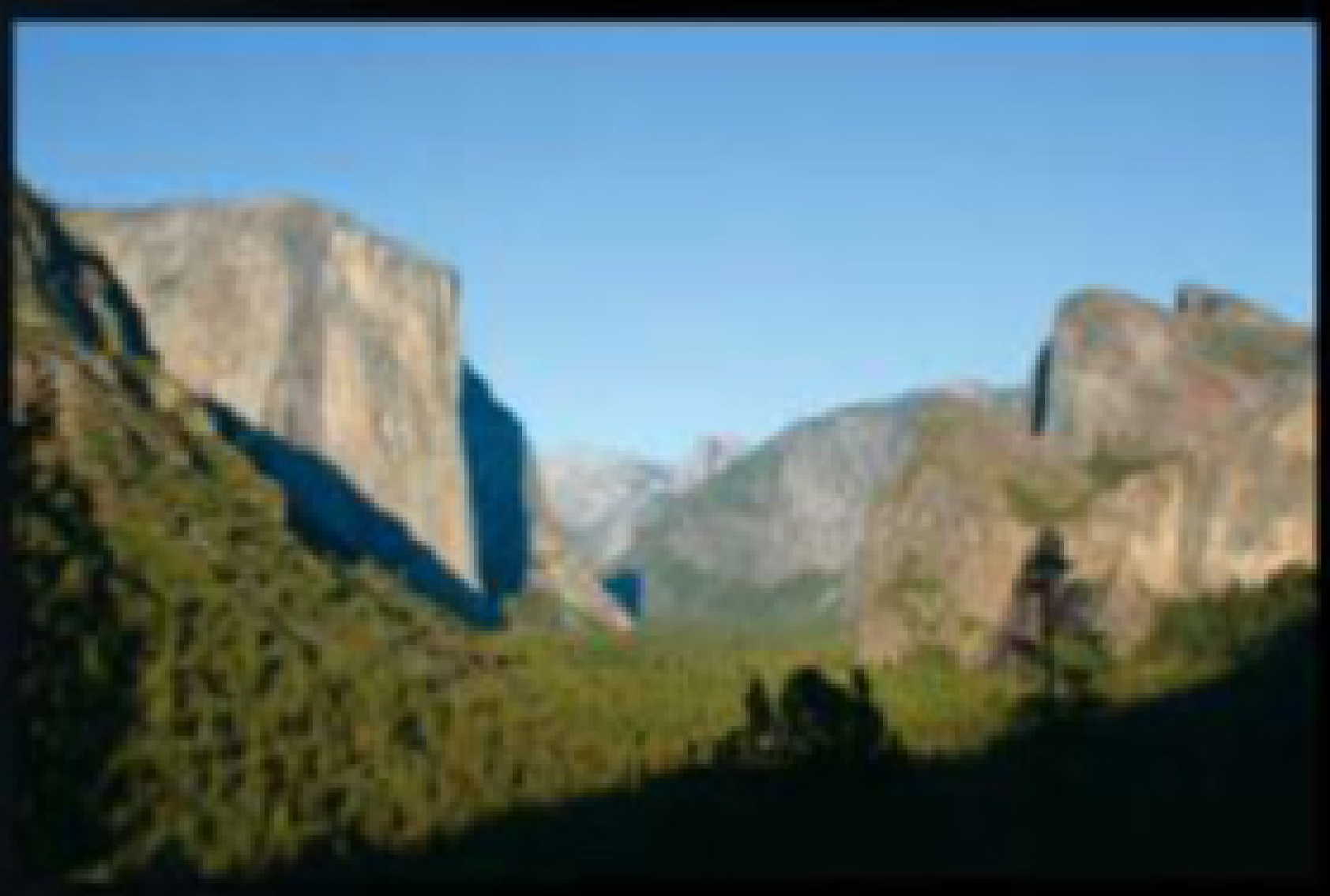
KEY DATES
ROALD AMUNDSEN'S EXPEDITION

Aug 1910	Jan 1911	Sept 1911	Dec 1911	Dec 1911
Amundsen and his team set off from Christiania, Denmark with nearly 100 Greenland dogs.	The boat reaches the Ross Ice Shelf, sailing closer to the Pole than Scott's team, giving them an advantage.	In their first bid to get closer to the Pole, bad weather forces them to race back to their base.	By reaching 88°23'S, the team is further south than anyone has ever travelled before.	Amundsen reaches the South Pole where he and his team place a Norwegian flag at the site.

DID YOU KNOW? Roald Amundsen beat Robert Scott to the South Pole by 34 days, despite Scott beginning eight weeks earlier

Surviving extreme Earth

The skills you need to journey into the wilderness and get out again alive



For many of us, the toughest conditions we'd ever have to face would probably be walking the dog in the bucketing rain. However, outside of the urban sprawl there are some places on Earth that aren't so hospitable to humans. While mankind has successfully populated large areas of the planet's land surface, there are still many places you wouldn't dare to venture unless you really enjoy a challenge or have just got horribly, horribly lost.

History is littered with people who have faced the biggest tests this planet has to offer, whether deliberately or accidentally, and lived to tell the tale, but many have fallen victim to frozen wastes or scorching plains. Even the best-prepared adventurers can come unstuck in the face of the amazing force of nature.

Over the next few pages we trek across deserts in search of water, dredge through jungles and scale icy mountains to uncover the dangers you're likely to come up against. Find out the equipment and skills needed to survive some of the most mind-boggling environments, where temperatures can plummet in hours, winds can reach breath-taking speeds and poisonous frogs can kill you where you stand.

We're not saying we will instantly turn you into the next Ranulph Fiennes, but it will hopefully give you a fighting chance should you find yourself in the depths of the Arctic Circle or in the middle of the Sahara. We still wouldn't recommend it though.

Beat the freeze

How to stay alive when you're freezing to death

Earth's north and south extremities are among the most inhospitable on the planet. Even in the summer months temperatures are near freezing and winds can reach up to 327 kilometres (200 miles) an hour, so it's no wonder the cold is the biggest killer here. If you're trekking across snowy wastes, you better have packed your thermals. Shrug on multiple layers of breathable fleeces and keep them dry. Any water will instantly freeze, as will any exposed flesh. Even nose hairs and eyelashes start icing over in minutes, so covering up is key.

Your body will respond quickly to the heat loss by tightening blood vessels near your skin. This is the reason we look paler when we're cold and why our fingers and toes become numb. Meanwhile, your muscles will start moving involuntarily, causing you to shiver. It can boost heat production up to five times, but that uses up a lot of energy so you'll need to keep eating and drinking. Consume six to eight litres (10.6 to 14 pints) of water every day and around 6,000 calories, three times the typical recommended daily allowance. You can get this by melting butter into your food or munching on chocolate and bacon, so it's not all bad!

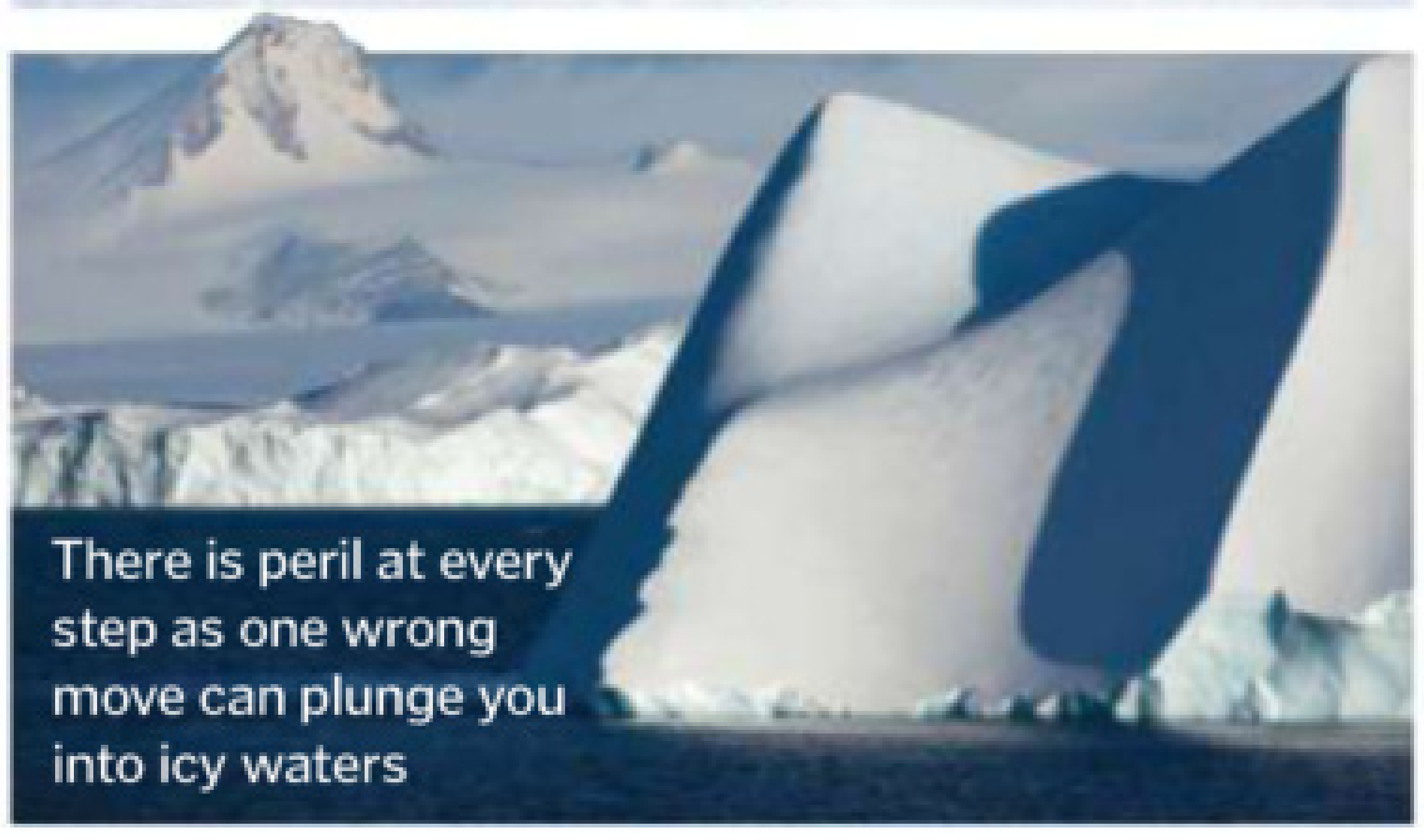
A word of warning, though: keep your eyes peeled. Hungry polar bears, particularly those with cubs to feed, can be aggressive and are masters of disguise. Flares and loud noises will often be enough to scare them away. You'll also need to watch your step, as slipping through a crack in the ice can send you plummeting into the freezing cold ocean. It's generally safe to walk on white ice, but grey ice is only ten to 15 centimetres (four to six inches) thick and prone to cracking, while black ice is to be avoided at all costs since it will have only just formed. Tread carefully, stay wrapped up and keep on the move if you want to have any hope of survival.

Amazing animal

The arctic fox is an incredible little animal, well adapted to living in one of the harshest environments on Earth. Its furry feet and short ears are ideally suited to conserving heat in the unforgiving, freezing environment. Its coat is also adaptable; while its habitat is snowy its fur is brilliant white, hiding it from both prey and predators. However, as the ice melts, its coat turns brown or grey to hide among the rocks of the region. The arctic fox is an omnivore, feasting on rodents, fish and birds, but it will also eat vegetation when meat is difficult to find.

The snowy wastes of the polar regions are difficult to navigate

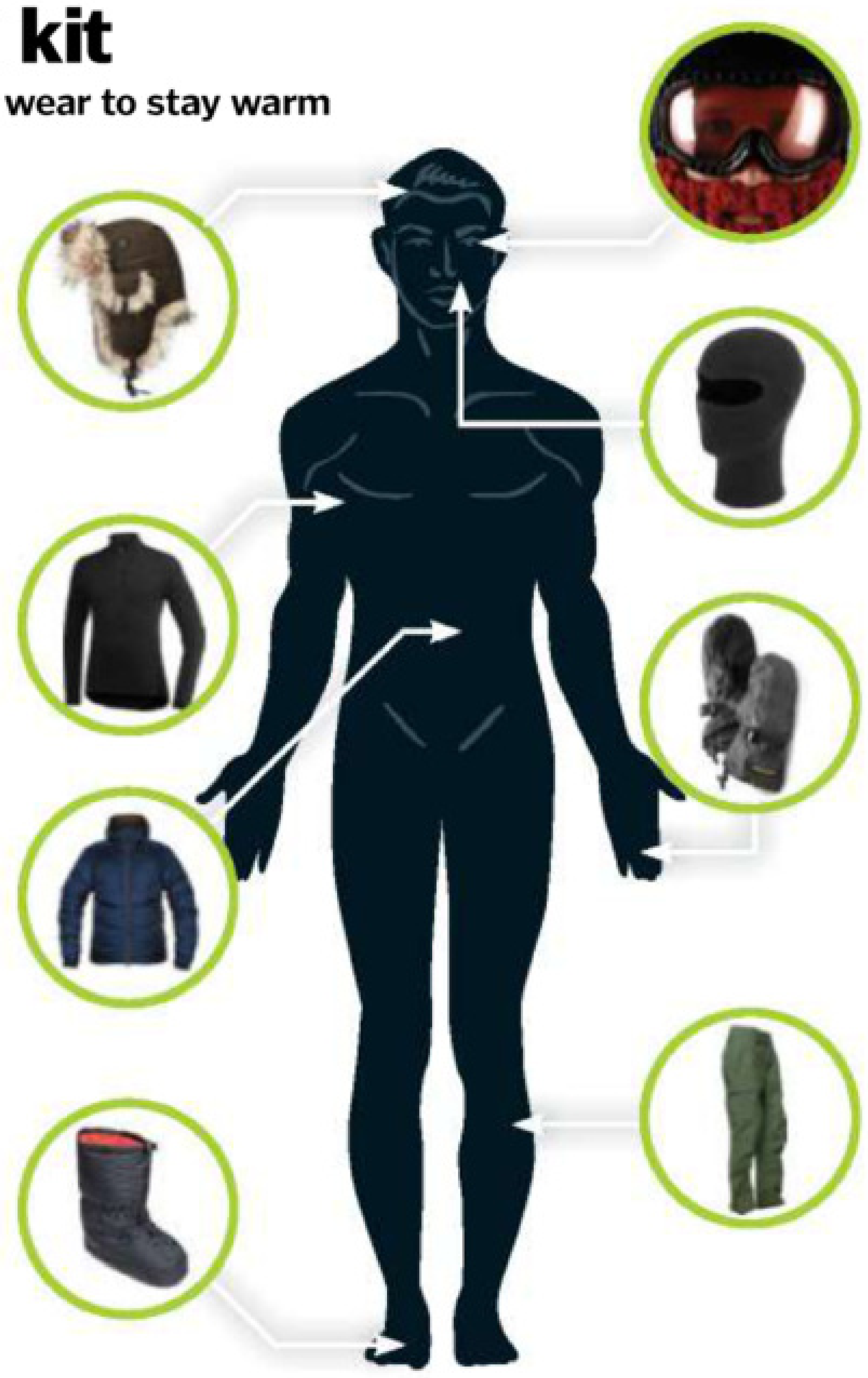
Polar bears are the Arctic's deadliest hunters


There is peril at every step as one wrong move can plunge you into icy waters

Little grows in this area so finding food is tough

Life-saving kit

A rundown of what to wear to stay warm



Hat
A hat with ear flaps that covers the head and neck is vital. A strap to secure it on the head will be useful in high winds.

Thermal shirt
Your base layer should be a thin, thermal insulating top that wicks any sweat away from your body.

Jacket
Your jacket will need to be both wind and waterproof to keep you dry and warm. Wrist holes in the cuffs keep it secured.

Boots
Warmth is vital – literally – so fleece-packed boots are good. Straps are better than laces but don't fasten them so tight it cuts off the blood supply.

Goggles
The best goggles have a photochromic lens to help ward off glare from the ice and make sure you see cracks and holes.

Balaclava
You'll need to cover up as much as possible, so a woollen balaclava will keep the most heat in.

Mittens
Although gloves offer more dexterity with actions, mittens are better as they keep your fingers together and much warmer.

Trousers
Waterproof and windproof trousers are a must. Make sure they are also breathable, however, as you don't want your legs to become sweaty and lose valuable fluid.

-93.2°c

COLDEST PLACE ON EARTH

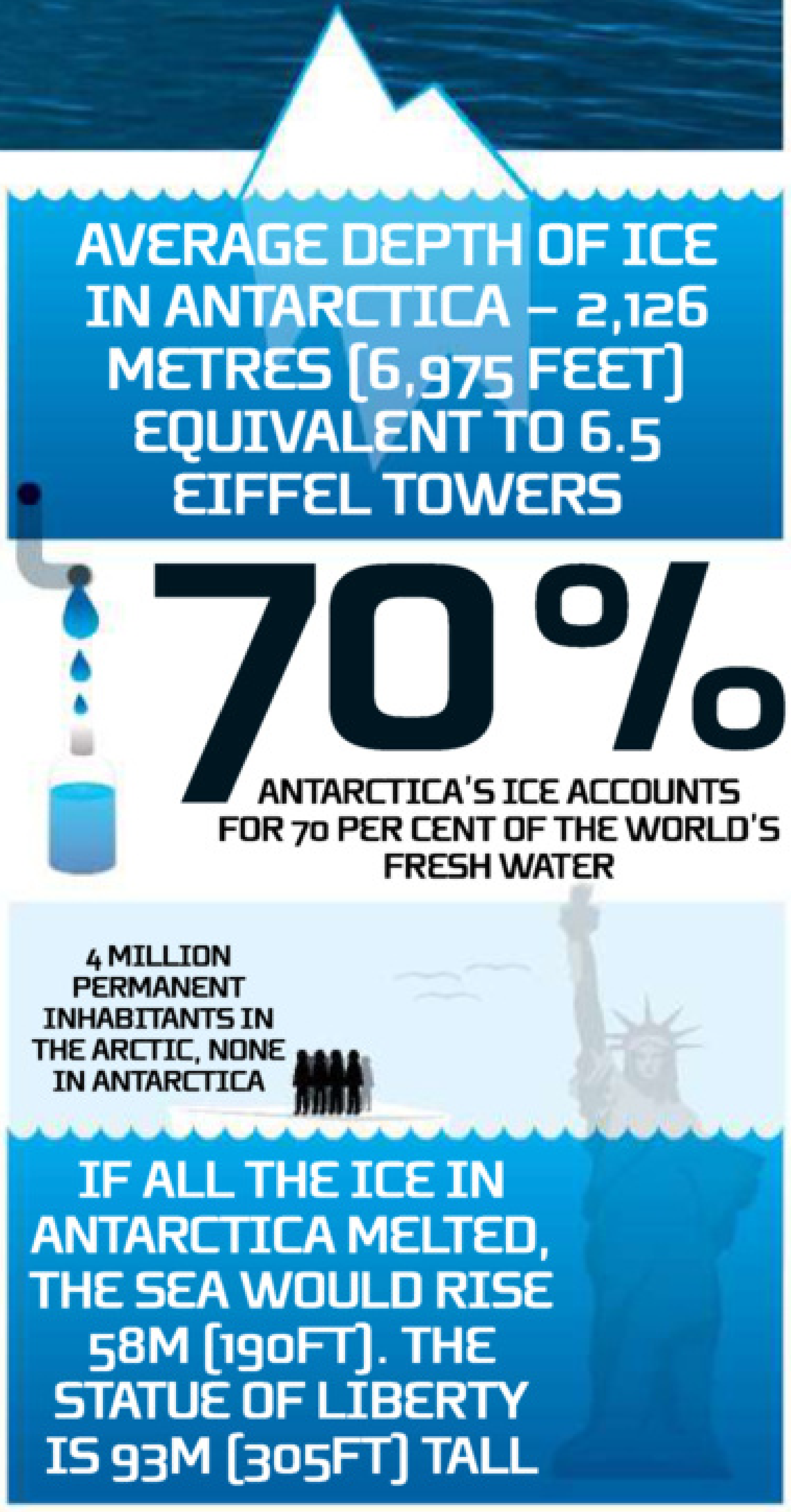
A bone-chilling temperature of -93.2°C (-135.8°F) was recorded in Antarctica in 2010 by satellite, making it the lowest temperature ever recorded on Earth.

DID YOU KNOW? *USA, Russia, Norway, Canada and Denmark all lay claim to territory in the Arctic, but none are allowed to own it*

Ice fishing

Make a hole in the ice with an auger – a kind of drill that bores large holes. The ice you bore on should be light grey and about 15 centimetres (six inches) deep. Produce a hole approximately 0.5 metres (1.5 feet) in diameter. Set up your chair one metre (three feet) away from the hole and hold your rod over the top of it, with the line dangling in the water. The rod should only be about a metre (three feet) long and made of a sturdy material. Drop the baited line down around two metres (seven feet) and wait for a bite. Reel it in and keep it chilled before cooking!

This simple tool can find you a life-saving source of food



AVERAGE DEPTH OF ICE IN ANTARCTICA – 2,126 METRES (6,975 FEET) EQUIVALENT TO 6.5 EIFFEL TOWERS

70%

ANTARCTICA'S ICE ACCOUNTS FOR 70 PER CENT OF THE WORLD'S FRESH WATER

4 MILLION PERMANENT INHABITANTS IN THE ARCTIC, NONE IN ANTARCTICA

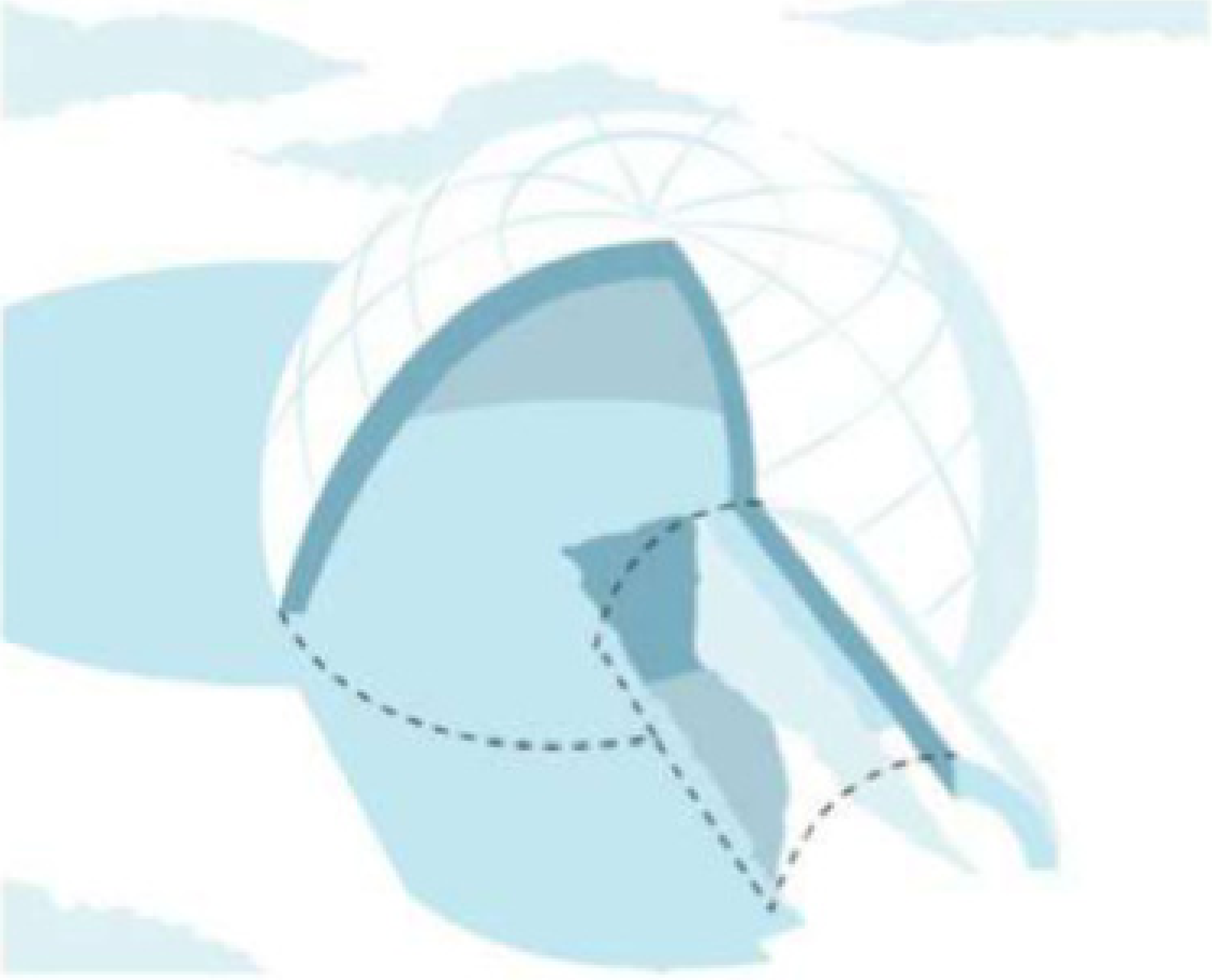
IF ALL THE ICE IN ANTARCTICA MELTED, THE SEA WOULD RISE 58M (190FT). THE STATUE OF LIBERTY IS 93M (305FT) TALL

Survive the night

Build an igloo for protection

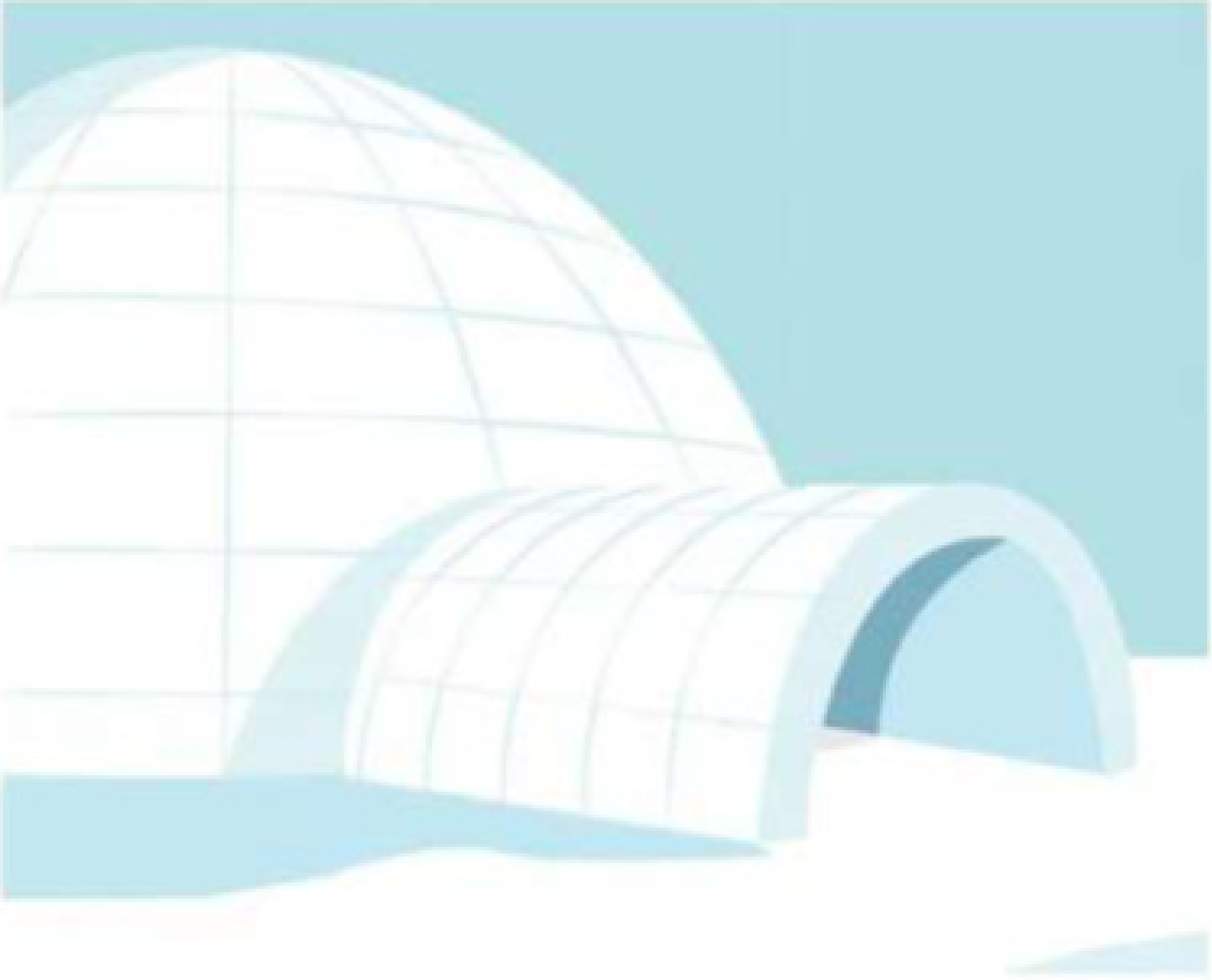
Find your spot

The first trick to making your igloo is to build it on the side of a slope. This will mean less building for you to do. Dig a trench in the snow around 0.6m (2ft) deep. Get in and slice out blocks of packed ice from either side of the trench to ensure they are nice and uniform.



Dig yourself in

Dig another trench into the side of the hill. It should be about 0.5 metres (1.6 feet) wide. This is the entrance trench. Leave a gap and dig another hole, but don't make it as deep as the entrance trench. This is your sleeping chamber, so make sure you fit in it!



Construct the walls

Stack the ice blocks in a circle around the sleeping trench, leaving a gap around the entrance trench. Over the entrance trench, stack the blocks in a semicircle. Make the entrance tunnel as small as possible to minimise heat loss. Rub water over the blocks to fuse them together.

Get out alive

Uncovering the dangers that lurk beneath the canopy of trees

Few places on Earth house quite as many things that can kill you in so many ways as the jungle. From snakes to poisonous frogs, berries to rivers, anyone walking through the jungle needs to have their wits about them at all times.

The most obvious threat will come from big animals like tigers and jaguars that inhabit the jungles of India and the rainforests of South America respectively. Your best bet for evading these huge predators is to stand still and hope you weren't seen, or run and hide. If you are spotted, make yourself as big as possible and shout loudly as this will surprise and intimidate them.

Don't be fooled into thinking the smaller critters pose less of a threat, though. Many can be deadlier than the big cats. The golden poison dart frog is particularly lethal to humans, as it has enough poison to kill ten adults. The poison is held in their skin, so eating or even touching one could have disastrous consequences. Add in the dangers of snakes, mosquitos, piranhas, crocodiles and bears, the jungle is not a place for the faint of heart. Take plenty of DEET-based insect repellent and make lots of noise as you travel so as to ward off creatures that would attack you out of fear or surprise.

While on your travels, be on the lookout for your next meal. On the menu will be fruit, plants, insects and fish, but you'll need a book to help weed out the edible from the poisonous. Avoid anything that's brightly coloured, because this is often an evolved defence mechanism to warn against eating that particular plant.

But while it's possible to survive for about 60 days without food in warm conditions, you'll last less than 72 hours without water. Always ensure you have a filtration device or water purification tablets to make the water safe, or catch rain before it has hit the ground to prevent catching diseases like cholera.

Although there are a multitude of things that can kill you in the jungle, being clued up on what you can and can't eat and how to avoid predator attacks will help enormously. If you're lost and ready to scream "Get me out of here!" then following water will take you out of the jungle to the end of the waterway. Ant and Dec almost certainly won't be there to meet you.

Tigers in the jungles of India are deadly predators

10

THE NUMBER OF ADULTS A GOLDEN POISON FROG COULD KILL IN ONE GO

Amazing animal

Bonobo monkeys are found in the jungles of the DR Congo and are one of our closest relatives. They share over 98 per cent of our DNA and have an astonishing ability to mimic human behaviour, including using tools and solving problems.

They have adapted superbly to life in the jungle, surviving on a varied diet of fruit, plant life small rodents, insects, and even soil. This flexibility means they will never go hungry.

They are extremely social animals, living together in groups of up to 100. The females move from group to group to prevent inbreeding and the males stay in their social groups for life.

STRANGE BUT TRUE
AGE TEST

What tells a sun bear's age?

A Rings on their teeth B Length of their tongue C Wrinkles on their forehead

Answer:
Much like you can do with trees, you can determine the real age of a sun bear by counting the rings on their teeth. Their jaws are incredibly strong and can break open nuts and coconuts quite easily, which also requires considerably strong teeth.

DID YOU KNOW? *Earth's largest rodent, the capybara, lives in South American jungles and can weigh as much as an adult human*

Avoid man-eating predators

Three steps to remaining undetected in the jungle

Cover your tracks

Predators like big cats are excellent trackers and they'll be keen to find you, especially if it's dinnertime. Walking in water will stop physical evidence of your movements, giving you a better chance of going undetected.

Camouflage

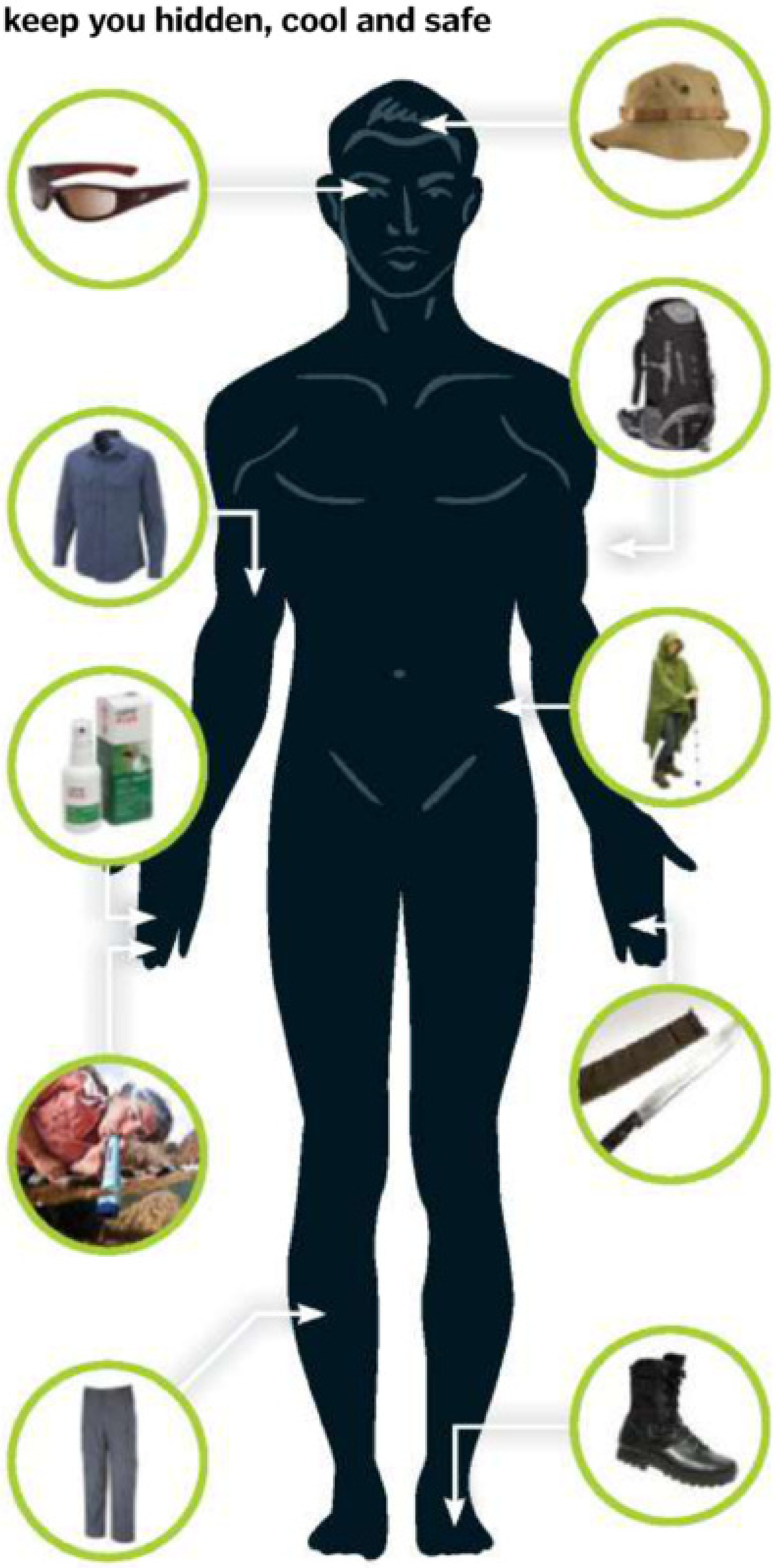
Hide yourself as you walk through the jungle using camouflage. If you don't have a specific outfit, coat yourself with mud and attaching leaves and foliage to your body will make you less likely to be spotted.

Cover your scent

Jackets lined with charcoal are excellent for preventing your natural odours from escaping into the environment. Otherwise, cover yourself in things like mud and strong smelling plants to mask your scent.

Jungle protection

The clothes and kit to keep you hidden, cool and safe



Sunglasses

The sunlight will be incredibly strong so you'll need some sunglasses with UV filters.

Long sleeve shirt

A light, breathable fabric will keep you cool, but make it baggy so mosquitos can't get to your skin.

Bug spray

Mosquitos carry a huge array of diseases, not least malaria, so 100 per cent DEET spray is vital.

LifeStraw

This device really could save your life. The filter inside the straw wipes out 99.99 per cent of bacteria in dirty water.

Trousers

Length is key here. You can't let your ankles get exposed because that's where mosquitos especially love to bite.

Hat

A large brimmed hat will protect you from bugs falling from the trees and keep you relatively hidden from animals above you.

Backpack

You'll need your hands free so a backpack is crucial. It needs to be waterproof, blend in with the environment and be comfortable.

Poncho

Sudden downpours are features of jungle and rainforest life, so a lightweight, quick-drying poncho is useful.

Machete

The jungle is a tough landscape to negotiate, so a large knife or machete will help you work your way through the thick and difficult undergrowth.

Boots

Your shoes don't want to be too thick and heavy because they'll wear you down. Sturdy trainers or Wellington boots will surprisingly be enough.

The edibility test

If you aren't a trained botanist, you might struggle to identify which plants are safe to eat. That's where the universal edibility test comes into play. Eat nothing and drink only water for eight hours before the test.

Your first task is to split up the plant you are testing into its individual components, such as the stem, root, leaf, flower and bud. Crush each part of the plant and, one-by-one, rub them on your skin to see if you have a bad reaction to it. If your skin blisters or forms a rash, it's unlikely to be good to eat.

If it's good, the next stage is to boil the plant, if possible. Hold the plant on your lip for a few minutes, removing instantly if it begins to burn. Finally, if the plant has passed the test so far, place it on your tongue. Again, if it begins to feel painful or look bad, spit it out and wash your mouth thoroughly. Remember though, tasting bad isn't the same as being poisonous!

Chew it for around 15 minutes and, if all still feels good, swallow it. Don't eat anything else for eight hours and see if you have any bad reaction to what you've eaten. If you're good, you've found a potentially life-saving food source!

Escape scorching heat

How to survive the extreme temperatures of the desert

While the polar regions are always bitterly cold no matter what time of day it is, one of the major challenges in surviving the desert is dealing with the ridiculous changes in temperature. In the midday Sun, the mercury can reach as high as 50 degrees Celsius (122 degrees Fahrenheit) in the Sahara, but drop to below freezing by night. Your best bet is to wear a loose-fitting robe. This will let air circulate around the body and you won't get nearly as hot and sticky. At night, when the temperature plummets, you can wrap it around you for warmth.

It is vital that you protect your head. If you think a touch of sunburn from staying by the pool on holiday is bad, that's nothing compared to the effects of walking all day in the parched desert. Even if it means burning another part of your body, wrap something around your head and neck so you don't succumb to sunstroke, which can lead to hallucinations and fainting.

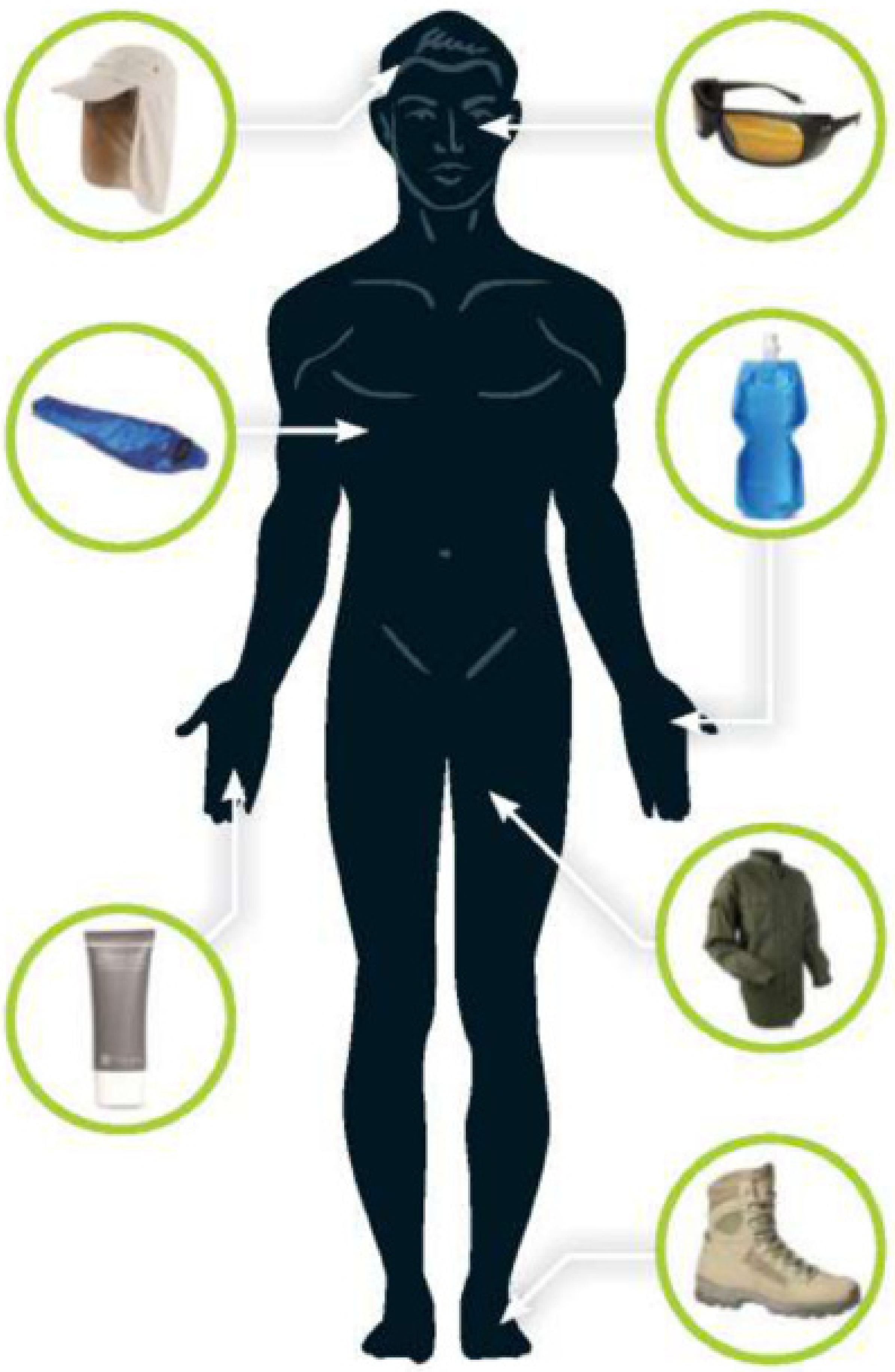
Other dangers in the desert will mostly come from scorpions. They hide in the sand and deliver a sting with their tail that can paralyse and eventually kill. Sturdy boots will protect you from these creepy crawlies, as well as making your travelling over sand much easier. While they don't make great pets, scorpions do provide a crucial source of nutrition. Picking them up by the tail just behind the stinger is the safest method and it will give you vital protein for your journey. Just don't eat the tail.

In the desert, you'll need to adjust your body clock. Aim to shelter during the day and travel at night. This has the dual benefit of avoiding the scorching sun and keeping you active during the freezing night. It also means you can keep on the right track easily by following the stars, hopefully leading to civilisation.

Shelter can come in the form of large rocks or cliffs. Alternatively, you can dig a trench down into the cooler sand and use clothing or some other material you have available to form a canopy over the top, secured by rocks or sand. As long as it is at an angle and not touching you, you'll be protected from the Sun's glare.

Desert dress

The essentials to surviving in the hottest places on Earth



Headwear
If you don't have any headwear, you could suffer with heatstroke, so protect your face and neck.

Sleeping bag
A brightly coloured blanket will be useful as it would enable any search party to find you, will keep you protected in the day and warm at night.

Sun cream
The baking temperatures will burn you in no time at all, so a high factor sun cream will provide at least some protection.

Sunglasses
The desert throws up an awful lot of sand and glare, so sunglasses will be absolutely vital.

Water bottle
This will be your greatest friend. Take small, regular sips and if you ever find a water source, fill it up as much as possible.

Shirt
Your clothes will need to be as loose fitting as possible to minimise sweating and dehydration.

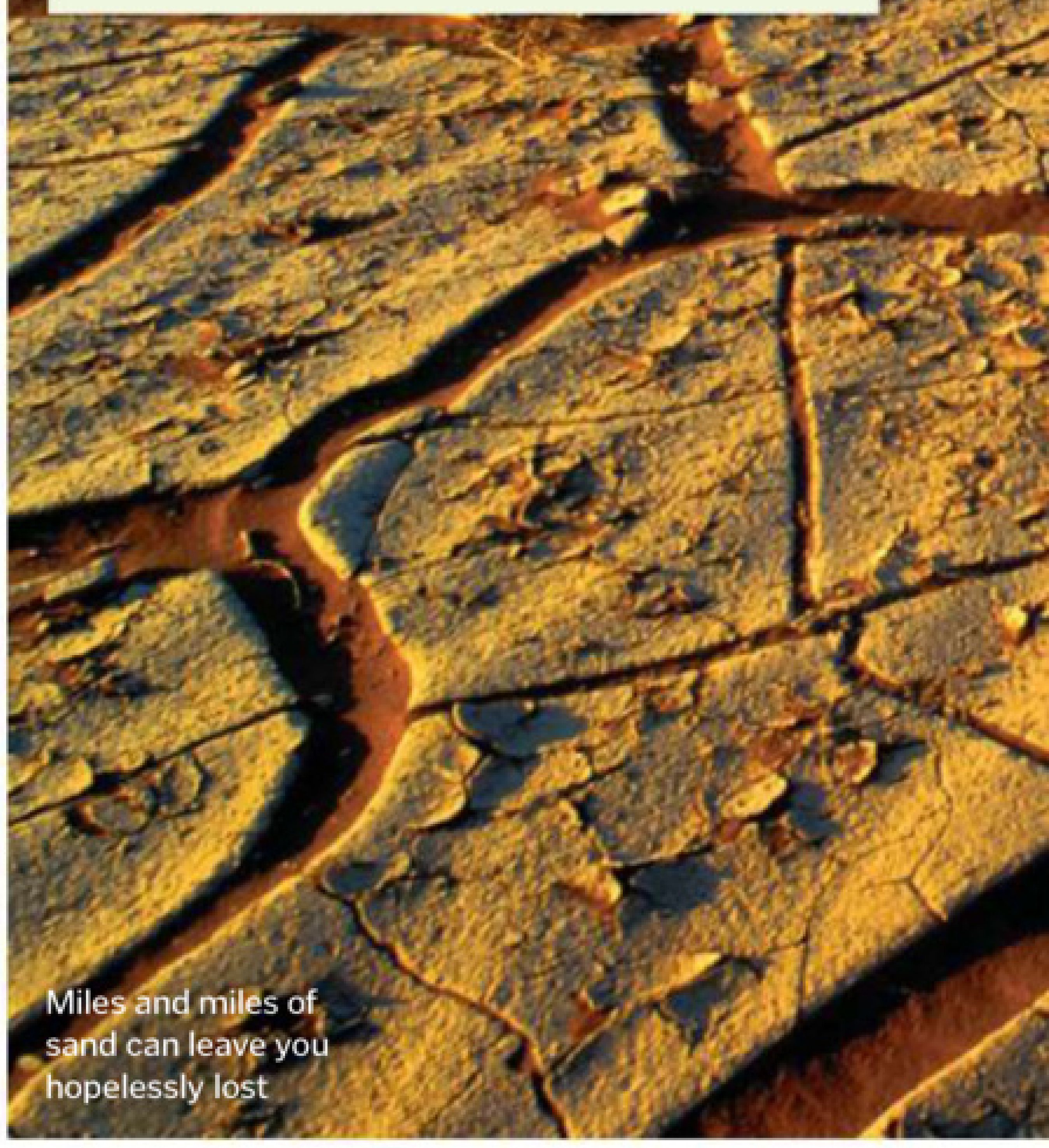
Footwear
Even though you'll be desperate for sandals, trainers or walking boots will give you grip and necessary protection.

Amazing animal

The camel is known as the ship of the desert, as this remarkable creature can travel without food or water for a long time.

Domesticated 3,000 years ago, camels have been an invaluable help to those who make their livelihood travelling the desert. They can carry 90kg (200lb) on their backs effortlessly and can travel up to 32km (20 mi) a day, with the added bonus of being able to last for at least a week without water and months without food.

Camels store fat in their hump to use as a food source and consume 145l (32gl) of water in one go, which they also store for later use. They have adapted wonderfully to the desert, developing a membrane across the eye and extra-long eyelashes to counteract sand storms. Their feet also are incredibly well protected with calluses and spread out for walking on sand.



Miles and miles of sand can leave you hopelessly lost

Finding your way around

The desert is not only barren and featureless, but it is also a moving entity. Therefore, finding your way around is tough. The easiest way to find your way around is with a compass, but if that isn't available, travel at night and use Polaris, the North Star, as your makeshift compass.

Even though they are always shifting, sand dunes can also provide useful navigation hints. They always build up at 90 degrees to the direction of the wind, as the wind pushes sand upward to form them, so even when there's no wind, if you know the wind is northerly, the dunes will go east to west and you can use that information to navigate.

If you are lucky enough to have any landmarks, try and make a straight path between them so you know you are going in a straight line.

HEAD 2 HEAD LARGEST NON-POLAR DESERTS

1. BIG

Gobi Desert

This 1.3mn km² (502,000mi²) rocky desert covers a large portion of China and Mongolia, experiencing harsh and dry winters.

2. BIGGER

Arabian Desert

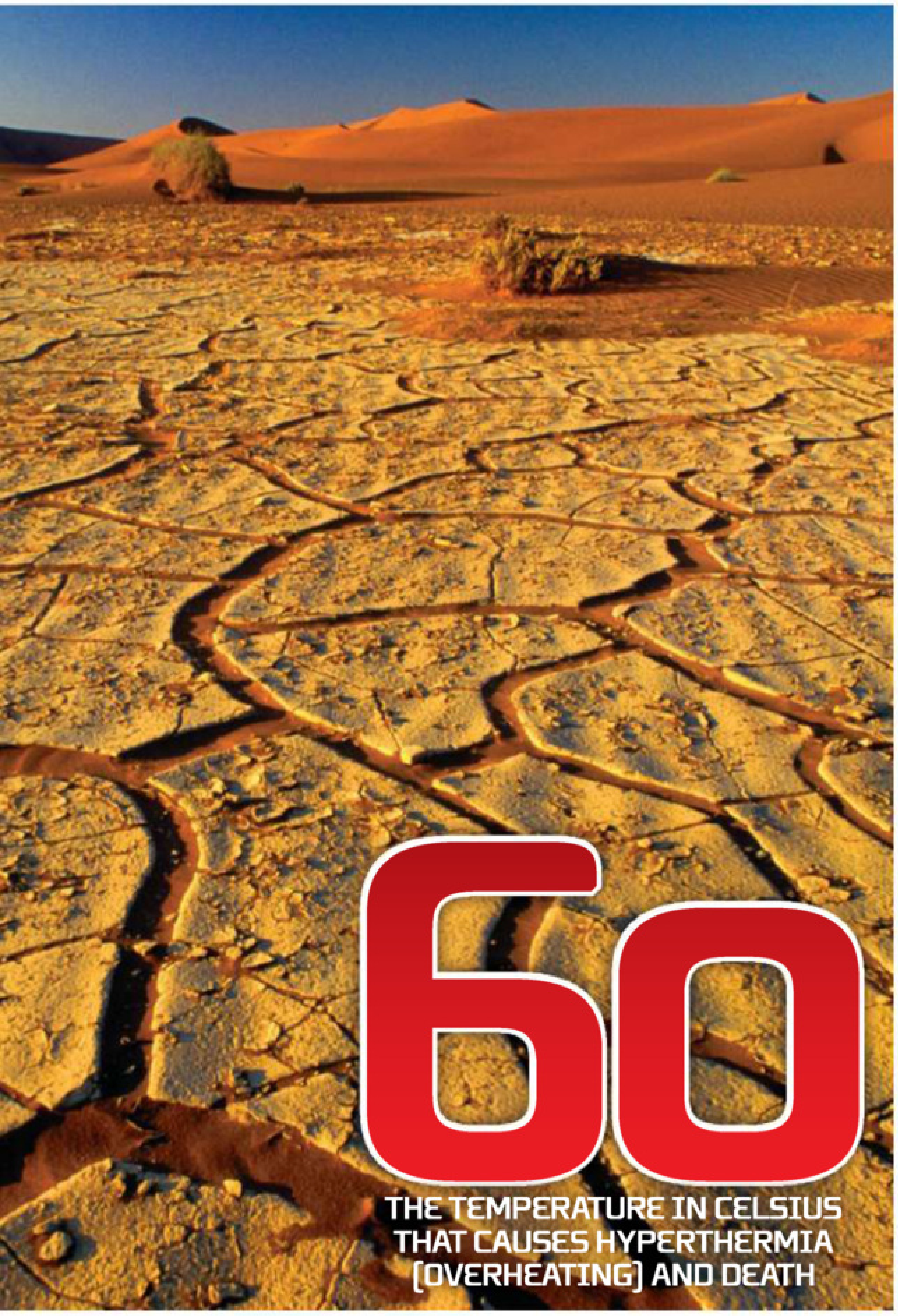
At a staggering 2.3mn km² (888,000mi²), the harsh Arabian Desert takes up most of the Arabian Peninsula.

3. BIGGEST

Sahara Desert

The most famous desert in the world measures 9.1mn km² (3.5mn mi²), making it over three times bigger than any other non-polar desert.

DID YOU KNOW? *Contrary to popular belief, drinking cactus water won't quench your thirst but make you very ill*



60

THE TEMPERATURE IN CELSIUS THAT CAUSES HYPERTHERMIA [OVERHEATING] AND DEATH

The plunging temperatures can leave you freezing cold without the right preparation

Fight extreme thirst

Locate the desert's most precious resource

Follow the wildlife

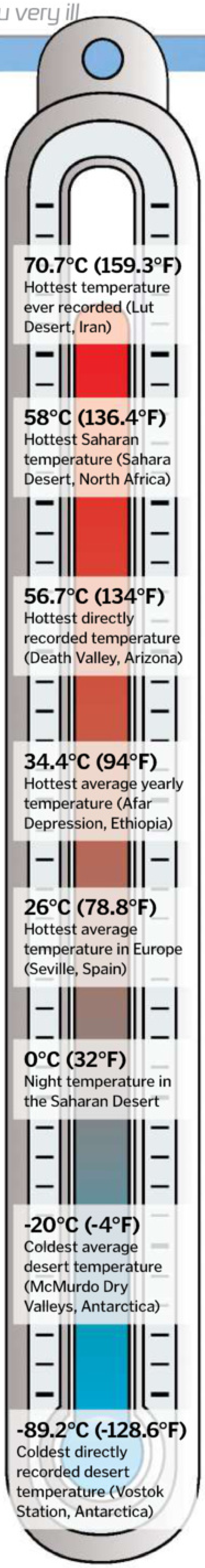
There are a number of birds and land animals that live in the desert and they all need water. Try and follow them wherever possible and hopefully they should lead you to a water source.

Shady cliffs

In your quest for precious shade, you might also be lucky enough to find water. Dips and ridges that face north could be housing puddles and pools in their shaded, cooler spots.

Grass is always greener

Plant life and vegetation means there is water around somewhere. Head down into valleys where there is plenty of greenery and even if there isn't a spring or pool around, you should be able to extract water from leaves or roots.



70.7°C (159.3°F)
Hottest temperature ever recorded (Lut Desert, Iran)

58°C (136.4°F)
Hottest Saharan temperature (Sahara Desert, North Africa)

56.7°C (134°F)
Hottest directly recorded temperature (Death Valley, Arizona)

34.4°C (94°F)
Hottest average yearly temperature (Afar Depression, Ethiopia)

26°C (78.8°F)
Hottest average temperature in Europe (Seville, Spain)

0°C (32°F)
Night temperature in the Saharan Desert

-20°C (-4°F)
Coldest average desert temperature (McMurdo Dry Valleys, Antarctica)

-89.2°C (-128.6°F)
Coldest directly recorded desert temperature (Vostok Station, Antarctica)

Battle life-threatening altitude

How to cross the world's most treacherous terrain

Mountains are the ultimate test of survival. They're prone to rapid changes in weather and it's near impossible to predict. Even if the base is warm and sunny, by the time you reach the summit, low cloud can blind you, rain can make the terrain slippery and the cold can freeze you.

Good preparation is essential and you'll need a lot of kit. Pack a rucksack with a map, compass and a flashlight or headtorch, along with a brightly coloured emergency blanket, and dress in thermals and waterproof and windproof clothing. You'll also need to keep well hydrated. A lack of fluid at high altitude will result in dizziness, intense headaches and even frostbite. If you don't have any water to hand, try to find a stream or melt some snow or ice to drink.

The altitude is a real issue for many mountaineers. As you climb higher, the air pressure reduces, meaning there is less oxygen for you to breathe. This lack of oxygen will cause your brain to reduce activity in all but the most important organs, making your limbs heavy and head dizzy. The most important thing to do is rest and re-oxygenate your body.

If you are trying to escape the mountain, the best way is to head downward, but this isn't always possible. Mountains have complicated structures and often there isn't an easy path down. If possible, put markers along your route to show where you have already been, to avoid walking in circles. As well as being potentially confusing, mountains also hide dangerous crevices. Keep your eyes peeled for breaks in the snow or ice and if you are ever unsure, try to find rocks or stones to throw in front of you that could give away a hidden abyss.

If the visibility does become too poor, the safest thing might be to bed down. Find a spot out of the wind and protected from any snow or rainfall, like a cave or overhanging cliff. Even though it might sound strange, pack your surroundings with snow, because it does have insulating properties. Pile yourself with as many layers as possible and this should provide the warmth so you can make it through the night and try to find your way out in the light.

Amazing animal

The mountain goat is amazingly adapted to life on the mountainside. Their hooves are curved and flexible to provide them more grip and traction on the treacherous slopes. Despite looking spindly and thin, their legs are actually very strong and they can leap surprisingly large distances.

They have two coats, a warm, woolly undercoat and a thinner but longer overcoat, which keeps the insulating undercoat dry. This system is how they can stand the cold temperatures long after bigger animals have given up and descended down the mountain in cold weather.

GoPros are a great way to record your adventure

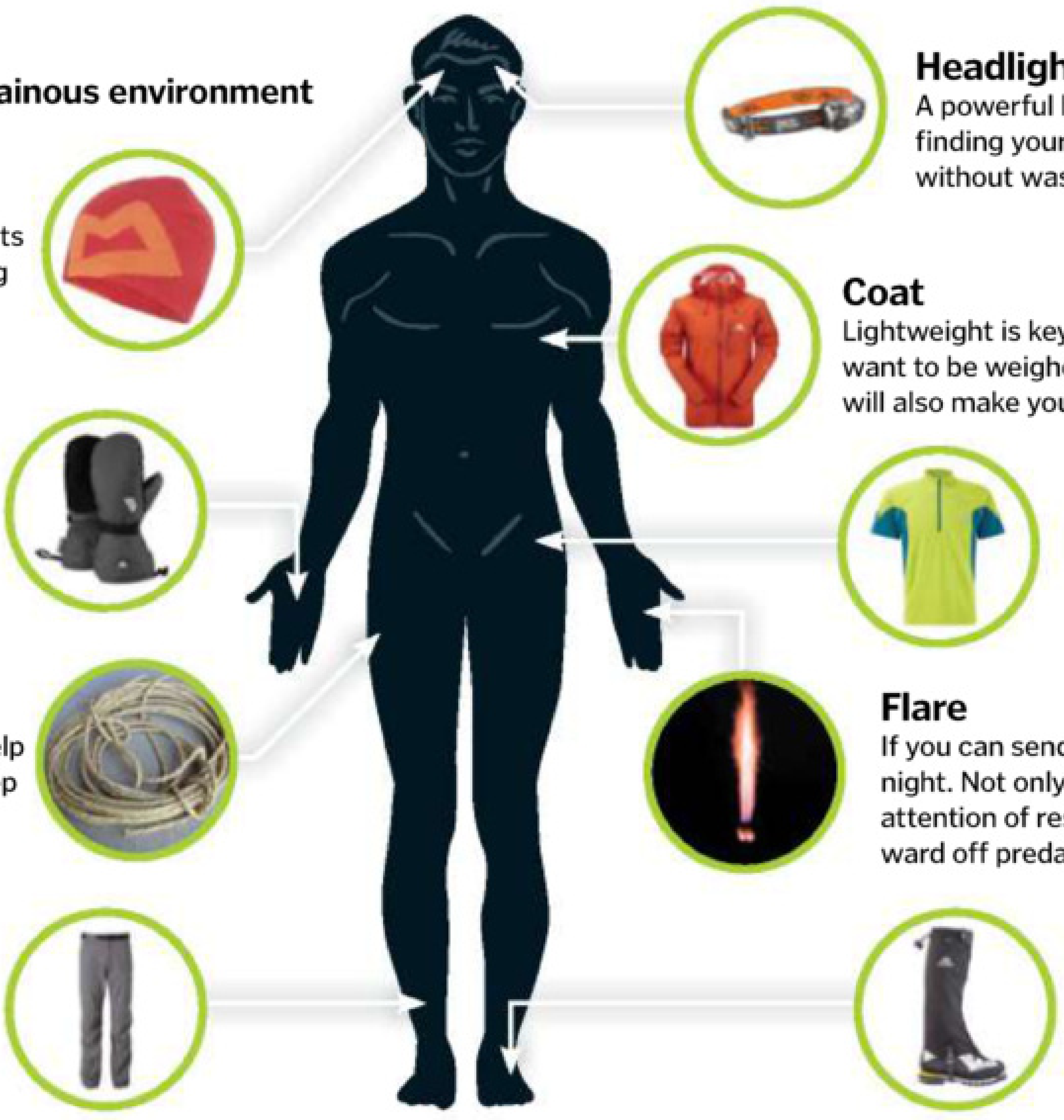
Keep a record

It's always handy to have a visual record of your travel by using a video recorder like the Hero3+ from GoPro. This camcorder is incredibly robust, lightweight and waterproof. It can also be attached onto helmets or bags, leaving your hands free to scale the treacherous mountainside.

Using a GoPro camera will also be useful as, once you get off the mountain to safety, you and a professional will be able to look over the footage, determine what went wrong and see how you could avoid getting stuck in the same situation again. The Hero3+ is available at **www.camerajungle.co.uk**.

Mountain gear

What you need to brave the harsh, mountainous environment



Headlight
A powerful headlight will be essential for finding your way around in darkness without wasting a hand on a torch.

Beanie
A tight-fitting hat will keep lots of heat in as well as not being likely to fly away!

Coat
Lightweight is key here because you don't want to be weighed down. Bright colours will also make you visible to rescuers.

Mittens
Although it would be useful to have fingers available for gripping ledges, it's more important to have your fingers warming each other.

T-shirt
A tight-fitting T-shirt made of breathable material will keep body heat in without making you sweat.

Rope
A strong and sturdy rope will help you protect yourself while asleep and also aid you in climbing or negotiating dangerous paths.

Flare
If you can send up a flare, do so at night. Not only will it attract the attention of rescuers, it might ward off predators.

Trousers
You need to keep dry and have items accessible, so a pair of waterproof trousers with zipped pockets will be the most useful.

Boots
A high-legged boot will keep the worst of the snow and water out, while the sole will need to be rugged and have tons of grip.

DID YOU KNOW? *The tallest volcano is Mauna Kea, as it starts 6,000m (19,685ft) below sea level, making it 10,205m (33,480ft) tall*

Keep the fire burning

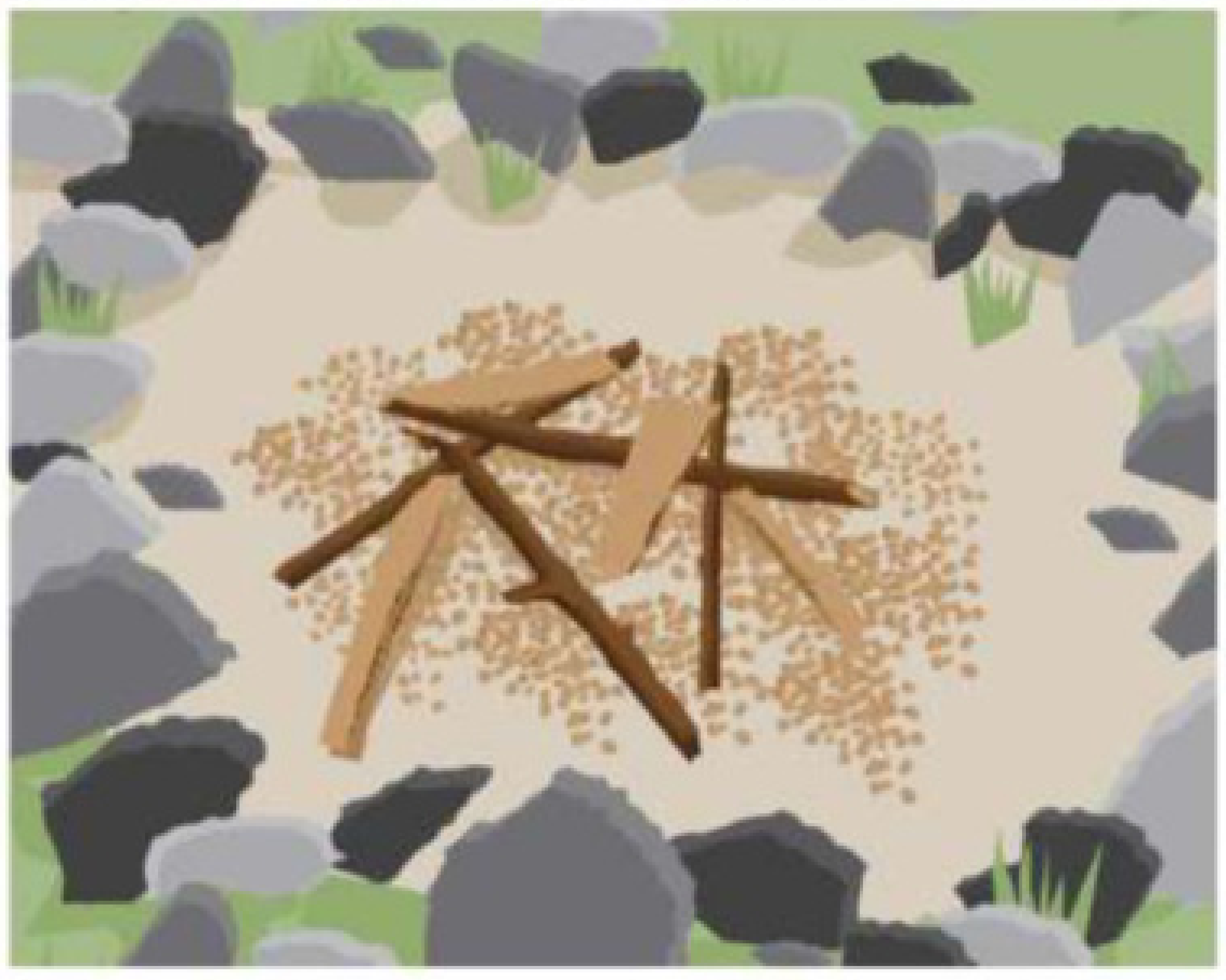
How to warm up on the mountainside

Find some wood

You'll want a variety of wood, from small sticks and twigs, all the way up to sizeable branches and logs. The smaller bits will light much more quickly while the bigger pieces will burn longer, hotter and form the bulk of the blaze.

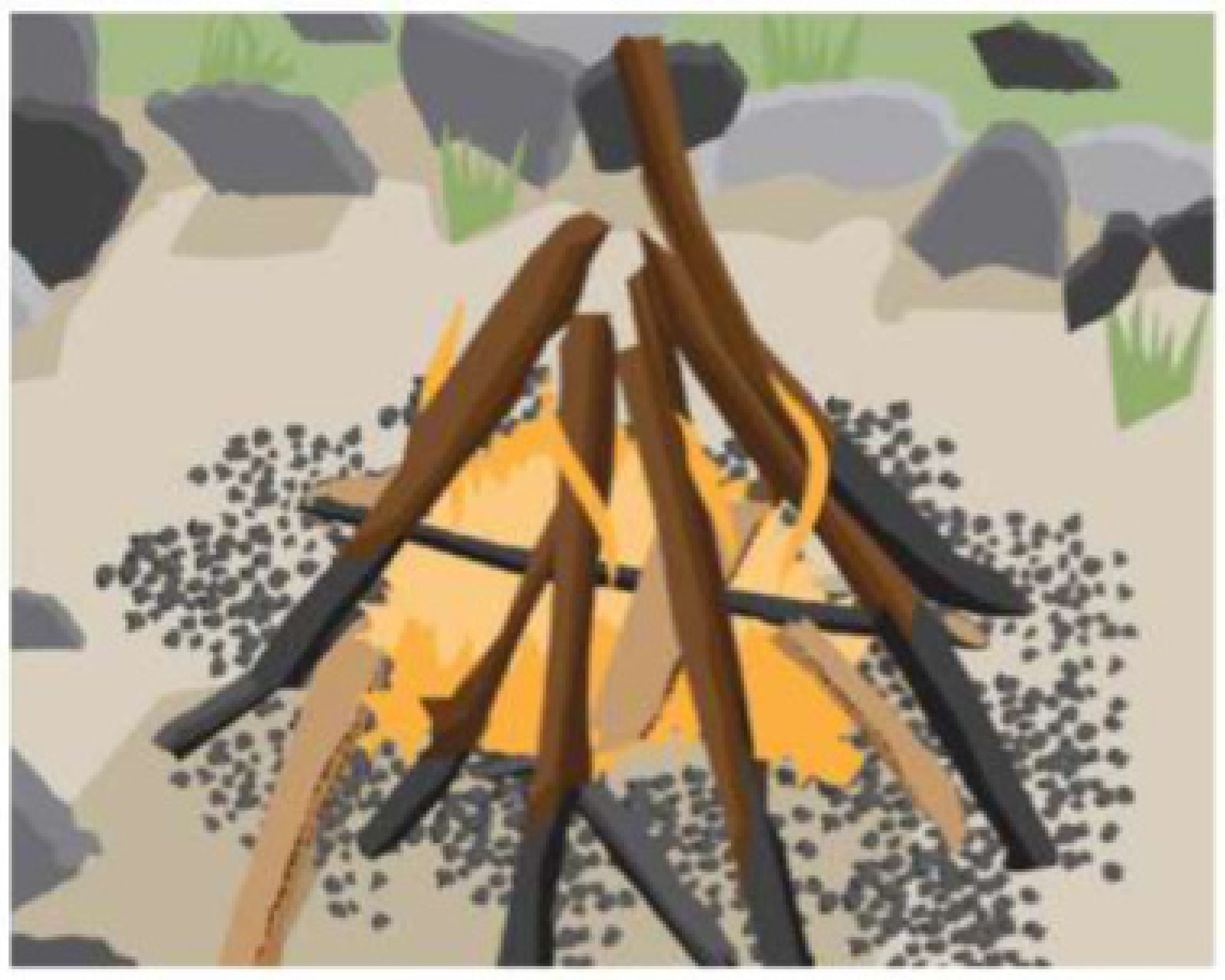
Build your base

Dig a small pit in the ground. Surround it with stones so the fire doesn't get out of control. Place the smallest bits of wood at the bottom of the pile, but leave some gaps to keep the fire supplied with the oxygen it needs to burn.



Light the fire

Place the larger branches and logs at an upwards angle, allowing the air to circulate and ensuring all the wood is getting burned evenly. Make sure everything is connected so fire can transfer from one piece of wood to another.



The weather can turn in an instant, so make sure you're prepared for anything

7500

HEIGHT IN METRES AT WHICH NEARLY A THIRD OF CLIMBERS GET HALLUCINATIONS

Crevices and cracks await the unwary traveller

Ben Fogle vs Mother Nature

TV's most charismatic survivalist has taken on ocean rows, desert marathons and polar expeditions. We got the chance to ask him how and, more importantly, why

Ben Fogle first exploded onto the survivalist scene as the star of BBC series *Castaway 2000*. 13 years later, he's riding a camel, commando. "The desert is unforgiving; I wish I had worn pants", he laughs, recalling the time he followed in the footsteps of legendary British adventurer Sir Wilfred Thesiger, crossing a brutal stretch of Middle Eastern desert. "We did it authentically, wearing original clothes as worn by Thesiger. He didn't wear undergarments and neither did I. But chafing aside, the trek across the Empty Quarter of Oman was the most enjoyable thing I've ever done because it was a lifelong ambition."

The 40-year-old's rapid adjustment to the challenging environment shouldn't really have come as a surprise, considering his varied, outdoorsy early years. "I spent all my summers in Canada at the cabin my late grandfather handbuilt on a lake. It was an idyllic *Swallows And Amazons* childhood of tree houses, fishing and raft building. I did a degree in Latin American studies after spending two years living in the colourful continent. I loved it and wanted to learn more. My degree included a one-year overseas programme so I went to Costa Rica. I would recommend Central and South America to anyone."

A stint on *Castaway 2000* followed, in which Fogle and 35 other men, women and children tried to build a community on the Scottish Island of Taransay. It was a hotbed of disagreement, argument and drama but he managed to rise above it, becoming one of the stars of the show. "I applied for *Castaway 2000* because I was looking for an excuse for adventure", he says. "I liked the idea of spending a whole year marooned on a remote island. The experience was life changing in every sense. It taught me so many life skills that still serve me today."

The social experiment ended a year later and back in London, the TV presenting jobs came flooding in. But with adventuring clearly in his blood, Ben sought another challenge and decided to take part in the Marathon des Sables (MdS). This epic six-day race, known as the toughest footrace in the world, takes runners around 240 kilometres (150 miles) through the Sahara Desert. Those taking part have to contend with scorching heat, terrible blisters and sand storms. Despite this, Ben managed to finish the race in less than 60 hours. "Anyone who has raced the MdS will know there are points when you want to give up, but it's not so easy in the middle of the Sahara", he explains. "You can't just jump on a bus."

Ben struggled through one of the toughest foot races in the world

The Race to the Pole required a lot of hard work and calories

Having conquered the Sahara Desert, two years later Ben entered the epic Atlantic Rowing Race with former Olympic rower James Cracknell. The pair crossed the 4,717 kilometres (2,931 miles) in 49 days, 19 hours and eight minutes, finishing second overall in the pairs classification. "I was looking for a challenge to make me stronger", he says. "I applied for the Atlantic Rowing Race and then set about finding myself a rowing partner. We spent a year getting ready for it. It was a gruelling experience, we capsized and nearly drowned but, as they say, what doesn't kill you makes you stronger."

5 TOP FACTS
THE LIFE OF BEN

The conservationist
1 While in South America, Ben Fogle worked on a turtle conservation project on the Mosquito Coast of Honduras, as well as volunteering in an Ecuadorian orphanage.

The driver
2 Fogle is a man of many talents, certified to skipper a variety of boats, yachts and dinghies as well as holding licenses for SCUBA diving and rally driving.

Famous mum
3 His mother is actress Julia Foster, best known for roles in *Alfie*, *The Loneliness Of The Long Distance Runner* and *Half A Sixpence*, among many others.

The boxer
4 He took on and beat *EastEnders*' Sid Owen in a charity boxing match in aid of Sport Relief back in 2004. He trained for six weeks for the fight.

Famous dad
5 Ben's father, Canadian-born Bruce Fogle, is also something of a celebrity, hosting many TV and radio shows in Britain in his role as a veterinarian.

DID YOU KNOW? The Marathon des Sables was created by Patrick Bauer, who crossed the Sahara in 12 days

Despite going to all corners of the globe, Ben still has more challenges to take on

Not content with rowing all the way across the second biggest ocean on the planet, the harsh Antarctic was Fogle's next challenge, once again teaming up with James Cracknell to take on the Race To The Pole, a team event that transports competitors to the southernmost tip of the planet. "Antarctica is the coldest, driest, windiest place on Earth," Fogle recalls. "It's a desolate, tough, unforgiving environment. We trained in Norway with the Marines and on a Swiss glacier with personal trainer Bernie Shrosbree. We had to bulk up before the race and take 5,000 calories of food per day for the race itself. The kit is essential to survival and we took advice from people who had previously trekked in Antarctica. The most important thing to remember is never sweat. Sweat and you die. It's difficult to race and not sweat."

In recent years there's been no avoiding a spot of perspiration, as his series *Extreme Dreams* took him to the jungles and mountains of South America and Africa, and his latest show *Storm City* investigates the effects of our planet's extreme weather. "One of the hardest things I have to face on my trips is disease and poverty", he says. "I still hate to see suffering in the world. It makes me feel guilty for what I have. Having said that, my job allows me to explore the world and meet incredible people."

As someone who's visited most of the hostile places on Earth, there aren't many options left for his next extreme expedition, but he's got a spot in mind. "The Moon. Watch this space."

© Alamy; Ed Crooks; Thinkstock

Cyclone vs anticyclone

What causes these spinning systems of air and how do they differ?

Cyclones and anticyclones are generated when areas of high and low air pressure collide. These are created by differences in temperature and humidity.

Air temperature affects the molecules' kinetic energy. The higher the temperature, the more the molecules move and collide. Humidity, on the other hand, affects the air itself. The atmosphere's main constituents – diatomic oxygen and nitrogen – are heavy compared to water vapour. The water in humid air replaces some of the heavier molecules, making it lighter than dry air, and therefore of a lower pressure.

An anticyclone is a region of high atmospheric pressure. The air descends through the system, spreading out sideways as it makes contact with the ground. The compressed air causes a rise in temperature – hence why anticyclones are associated with summer weather and dry winter days.

In contrast, a cyclone is centred around a region of low pressure. Inward spinning winds draw air upwards into the system – as it rises, water vapour cools and condenses, resulting in cloudy weather and storms.

Hurricanes and cyclones form as a result of rapid shifts in air pressure and temperature

© NASA; Thinkstock

Megafloods

Epic floods shaped our world but could they happen again today?

North-west America hosts some of the strangest and most spectacular landforms on our planet. Scarred into the black rock are giant channels carved out by water – the largest is the Grand Coulee in Washington at 97 kilometres (60 miles) long.

In 1922, geologist J Harlen Bretz began investigating how these channels formed. He initially attributed them to the slow action of rivers, but the more he looked into it, the more unusual landforms he discovered. Among them were piles of gravel some ten storeys high and hills shaped like boat prows.

These gargantuan features were best explained by water tearing through the landscape – an unimaginably massive megaflood. The prow-shaped hills pointed in the direction of flow, while the gravel was dropped when the floodwaters receded.

Bretz tracked the source of this colossal torrent – possibly the largest flood in history – to the glacial Lake Missoula. During the last ice age, this lake formed behind a 610-metre (2,000-foot)-tall wall of ice. When this dam failed, around 15,000 years ago, the lake emptied in just 48 hours and the waters carved the Grand Coulee. They left ripples, like those on a streambed, but a monstrous nine metres (30 feet) high. The process would repeat itself over the next 2,000 years, carving out more colossal landmarks in North America.

Lake Missoula might be the biggest known megaflood, but it's by no means the only one. Indeed, during the last 1.8 million years, at least 27 gigantic freshwater floods have shaped our planet, carrying more than 100,000 cubic metres (3.5 million cubic feet) of water every second – equivalent to over 30 Niagara Falls!

We know less about giant floods from further back in Earth's history. "As you go back in time, you don't have the landforms preserved," says ice-age geologist Professor Philip Gibbard.

Water escaping from natural dams or glaciers is responsible for many of the biggest floods, including Lake Missoula. Gibbard continues: "You get substantial flooding if a major dam floods and releases water."

Among them is the megaflood that turned Britain into an island around 450,000 to 200,000 years ago, when sea levels were lower than today. A gigantic lake formed in what is today's North Sea behind a chalk ridge that once connected Britain to France by land. When the lake punched through the natural dam, floodwaters gouged a huge valley into the English Channel seabed (see the thermal imagery on the opposite page).

Other massive floods occurred when sea levels rose after an arid spell. For instance, around 5.3 million years ago, Atlantic waters spilled into the dried-up Mediterranean; the ocean eroded a channel through the Strait of Gibraltar, filling the sea in as little as two years.

5 TOP FACTS FLOOD DEFENCES

Maeslant Barrier

1 Earth's largest movable storm surge barrier defends Netherlands' Rotterdam from floods. It spans a waterway 360m (1,200ft) across – as wide as the Eiffel Tower is tall.

Thames Barrier

2 This movable flood barrier is one of Earth's biggest and protects London against the North Sea. When raised, each of its ten steel gates is the height of a five-storey building.

St Petersburg Dam

3 The gigantic barrier includes 11 dams and is topped by a six-lane motorway. It was completed in 2011 after 300 years of almost yearly floods in the former Russian capital.

West Closure Complex

4 The world's biggest pump station – designed to blast floodwaters back out to sea – is among £8.5bn ($14bn) of works to protect New Orleans from future hurricanes.

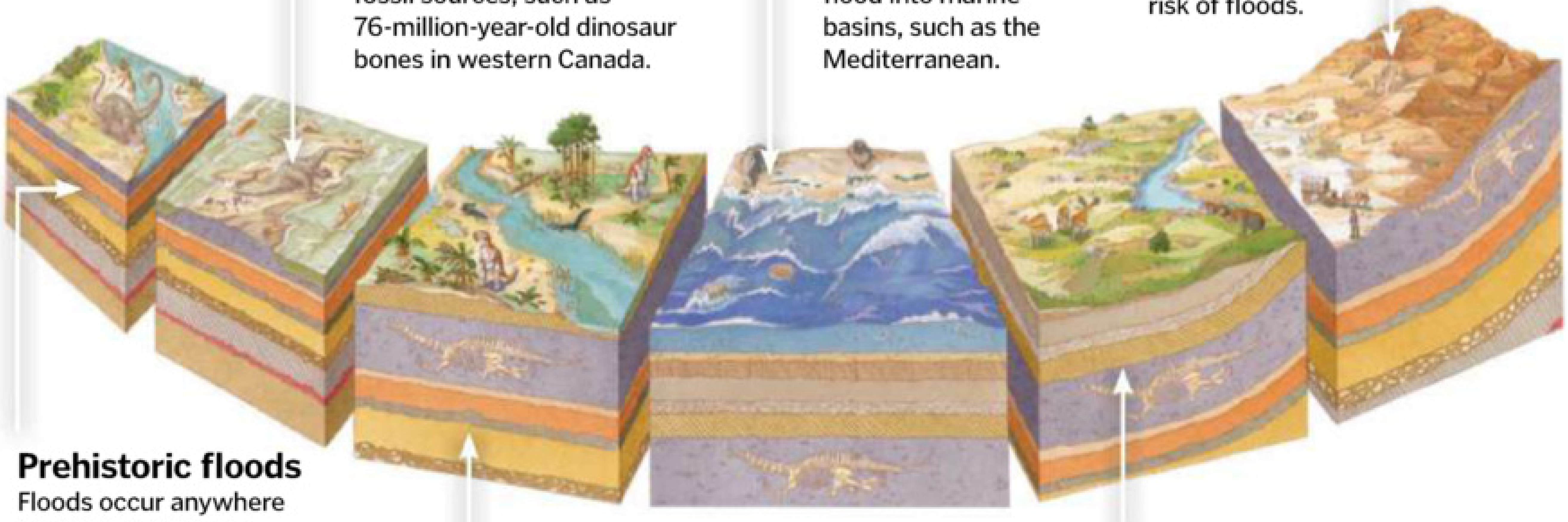
Delta Works

5 Described by some as a 'wonder of the world', this huge series of 300 dams, sluices and storm surge barriers protects the low-lying Netherlands from the sea.

DID YOU KNOW? *Nearly half of flash-flood deaths occur in vehicles. Just 0.6m (2ft) of water can set a car afloat*

Water world

What role have ancient floods played in forming the planet we know today?



Dinosaur graveyard
Ancient floods drowned prehistoric species, creating fossil sources, such as 76-million-year-old dinosaur bones in western Canada.

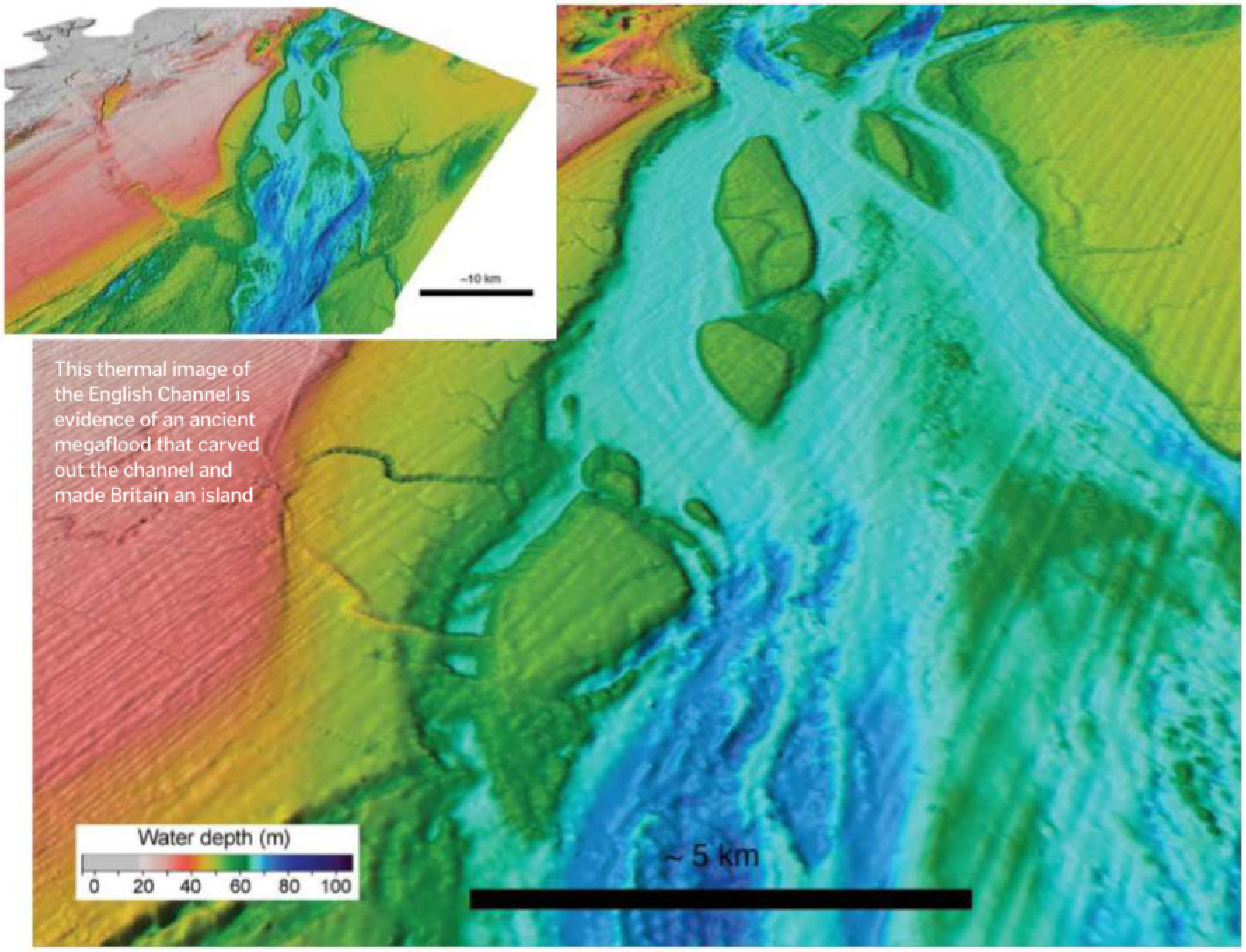
Sea level rise
Rising sea levels caused saltwater to flood into marine basins, such as the Mediterranean.

Present day
Humans build on flood plains, dam rivers and chop down trees – increasing the risk of floods.

Prehistoric floods
Floods occur anywhere there is water. When floodwaters retreat, nutrient-rich sediments are often left behind.

Ancient sediments
Evidence of prehistoric megafloods includes mineral deposits – such as microscopic zircon grains – dropped far downstream from their source.

Ice ages
Sea levels fell during ice ages. The ice formed natural dams across rivers, which collapsed to cause megafloods.



This thermal image of the English Channel is evidence of an ancient megaflood that carved out the channel and made Britain an island

Biggest floods in history

1 Altai Mountains, Asia

What may possibly be the biggest flood of all time occurred around 12,000 years ago. Ice dams collapsed on two interconnected lakes, emptying them into the Mediterranean Sea in an estimated five hours.

2 Wasilla, Alaska

When the glacial Lake Atna in Alaska breached a natural ice dam around 17,000 years ago, the megaflood released as much as 1,400km^3 (336mi^3) of water – that's enough to cover the area of Washington DC in water 8km (5mi) deep!

3 Bonneville flood, North America

During a wet period 14,500 years ago, Lake Bonneville overflowed its basin. The floodwaters stripped soil, filled a 100m (330ft)-deep canyon to the brim and created immense and powerful waterfalls.

4 Yarlung-Tsangpo Gorge, Tibet

Gigantic lakes trapped in the Himalayas by ice dams helped erode this majestic gorge – which is possibly Earth's deepest. Evidence exists of several megafloods in the gorge during the last 2.5 million years.

5 Black Sea deluge

The biblical story of Noah and the great flood might well be based on a real historical event. Rising sea levels around 7,500 years ago may have flooded the Black Sea, destroying human settlements in the process.

Megafloods can also have a massive impact on the climate. The Lake Agassiz flood, for example, is blamed for a cold spell 12,900 years ago that sent North America's large mammals, like the woolly mammoth, extinct. Floodwaters poured into the North Atlantic, interfering with the ocean circulation that brings warm water to the poles, known as the Gulf Stream.

Fortunately floods as large as Lake Agassiz or Missoula are unlikely to happen today. The biggest deluges were associated with giant ice sheets that swathed the northern hemisphere during the last ice ages. The ice released torrents of meltwater and trapped huge lakes behind ice dams, which gradually succumbed to global warming. Only the Greenland and Antarctic ice sheets, and a few ice caps, remain.

But that doesn't count megafloods out altogether. Among the 27 known big freshwater floods in the last 1.8 million years, eight occurred after 1900. According to Gibbard: "We could experience a megaflood today. Look no further than Iceland where we see jökulhlaup."

Jökulhlaup, or glacier bursts, occur when a volcano erupts under an ice cap, such as the 1996 Vatnajökull eruption in south-east Iceland. A torrent of meltwater flooded from beneath the ice, wiping out anything that stood in its way, including bridges, roads and power lines. It's estimated that peak flows reached 50,000 cubic metres (1.8 million cubic feet) of water per second in this massive jökulhlaup.

Another cause of giant floods, says Gibbard, is where "you have a volcanic lake, and the volcano erupts and breaches the barrier holding the water in the crater. You can get a deadly mudflow, sweeping away everything in its path." An example is Lake Taupo, New Zealand's largest lake, which flooded during an eruption some 1,800 years ago.

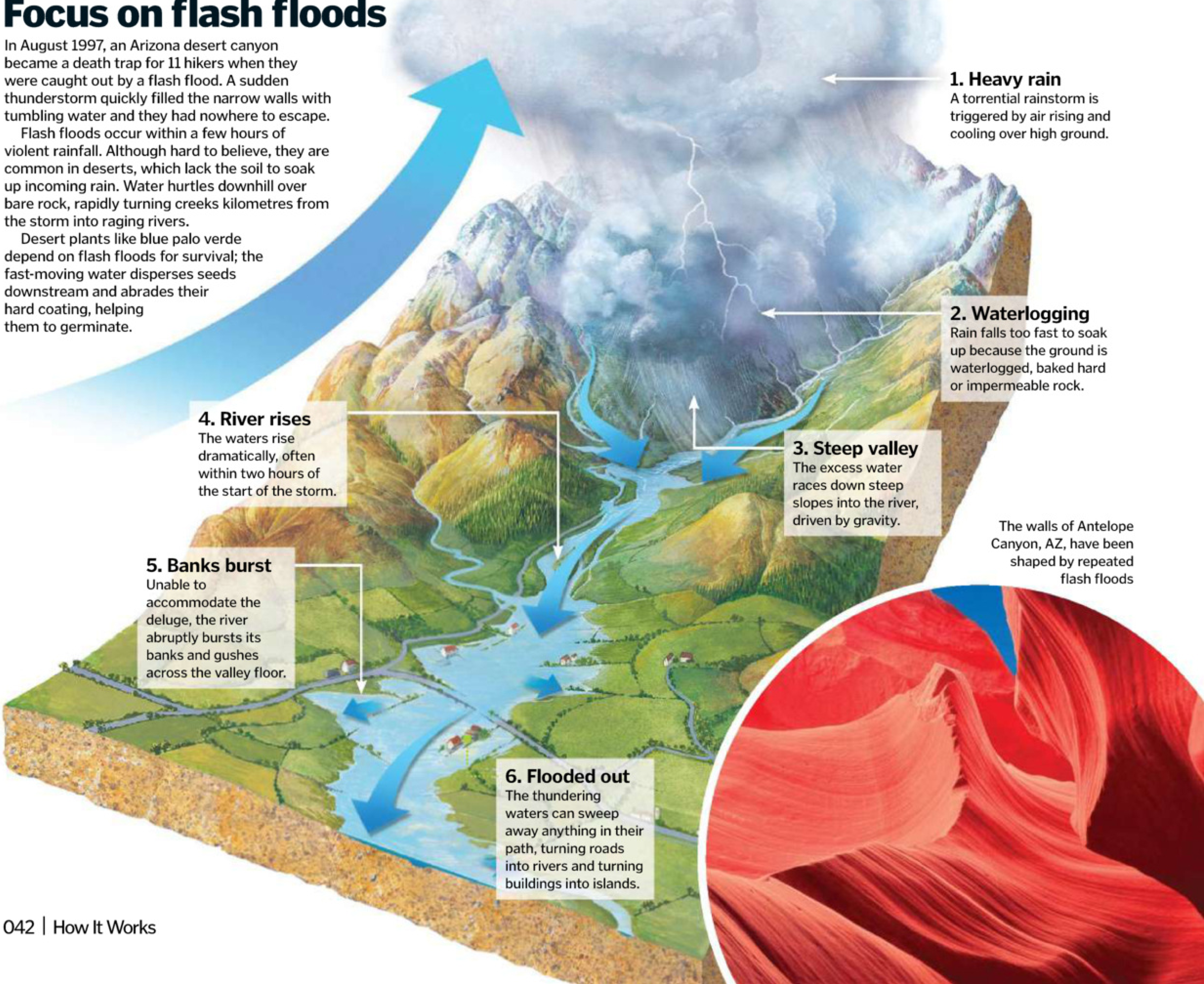
Debris from volcanoes can also block rivers. An eruption in Mount St Helens about 2,500 years ago caused Spirit Lake to empty catastrophically. More than 260,000 cubic metres (9.2 million cubic feet) of water per second flooded downstream. This was like a bathtub overflowing by comparison to Lake Missoula, though, which emptied at an incomprehensible 17 million cubic metres (600 million cubic feet) per second. Similar floods would have been likely after the 1980 eruption

Focus on flash floods

In August 1997, an Arizona desert canyon became a death trap for 11 hikers when they were caught out by a flash flood. A sudden thunderstorm quickly filled the narrow walls with tumbling water and they had nowhere to escape.

Flash floods occur within a few hours of violent rainfall. Although hard to believe, they are common in deserts, which lack the soil to soak up incoming rain. Water hurtles downhill over bare rock, rapidly turning creeks kilometres from the storm into raging rivers.

Desert plants like blue palo verde depend on flash floods for survival; the fast-moving water disperses seeds downstream and abrades their hard coating, helping them to germinate.



1. Heavy rain
A torrential rainstorm is triggered by air rising and cooling over high ground.

2. Waterlogging
Rain falls too fast to soak up because the ground is waterlogged, baked hard or impermeable rock.

3. Steep valley
The excess water races down steep slopes into the river, driven by gravity.

4. River rises
The waters rise dramatically, often within two hours of the start of the storm.

5. Banks burst
Unable to accommodate the deluge, the river abruptly bursts its banks and gushes across the valley floor.

6. Flooded out
The thundering waters can sweep away anything in their path, turning roads into rivers and turning buildings into islands.

The walls of Antelope Canyon, AZ, have been shaped by repeated flash floods

DID YOU KNOW? *Floods are the deadliest natural disaster, responsible for an estimated 500,000 deaths between 1980 and 2009*

of Mount St Helen's if mitigation measures weren't undertaken and the lake had not been drained via a pipeline.

So how do these megafloods compare to more common flooding events, like we've seen in recent months? "They're orders of magnitude greater," explains Gibbard: "We're talking stuff that's incredibly dramatic. Much larger scale than conventional flooding of rivers."

Rivers bursting their banks are the most common cause of flooding today. Excessive rain or rapid snowmelt can overfill a river channel, causing water to spill out over low-lying land. Waterlogged or parched soil can also cause water levels to rise rapidly. Even a little rainfall cannot be soaked up by the ground so rush straight into the river, causing a flood.

Human activity – such as building hard tarmac roads – is making river flooding even worse, warns Gibbard. "The inevitable consequence of covering the landscape with impermeable materials is like wrapping it in a polythene bag. [More and more] water runs straight into our rivers."

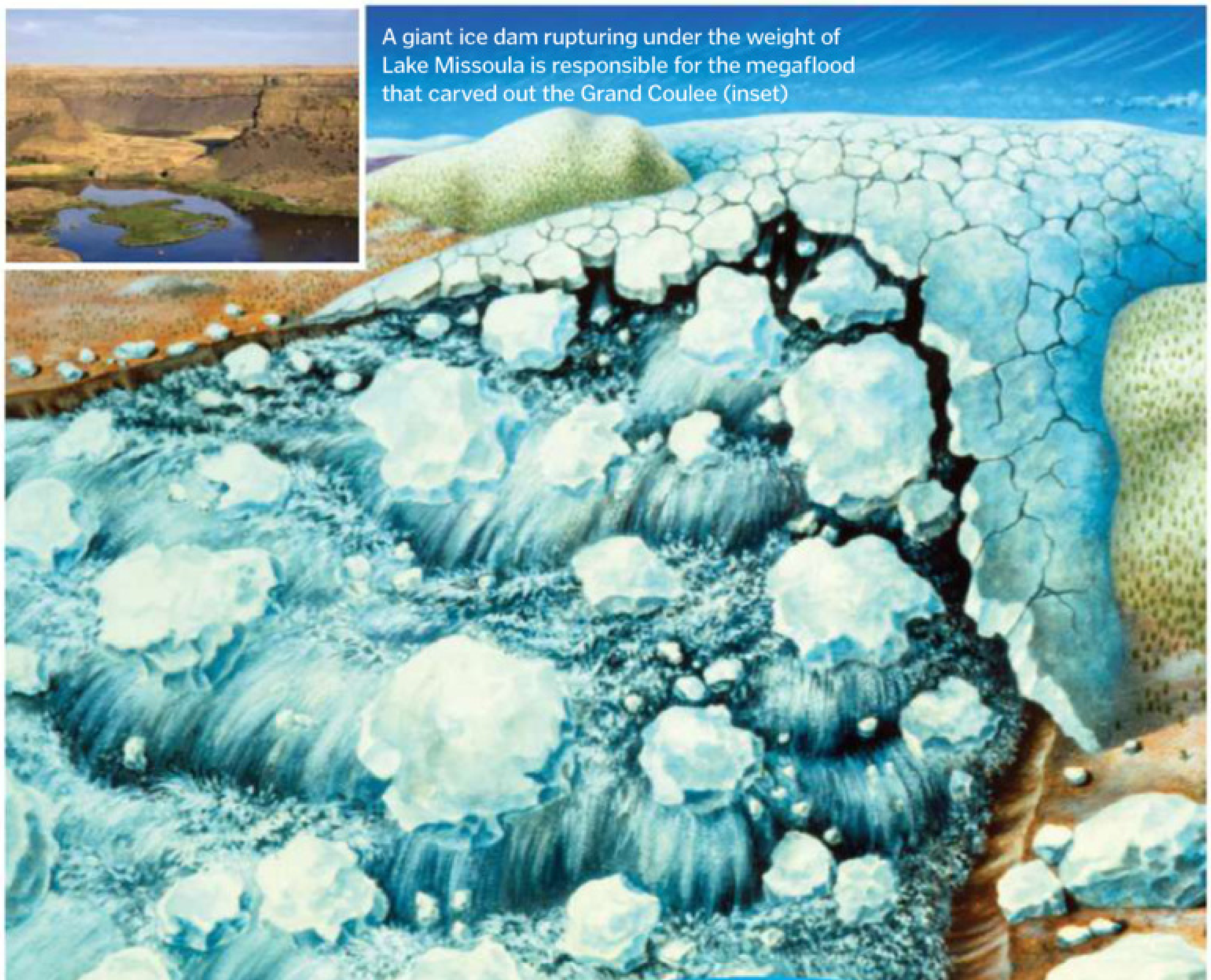
With sea levels predicted to rise dramatically this century – and climate change likely to boost storm power and frequency – the risk of coastal flooding is also on the rise.

Coastal flooding occurs when a storm blows seawater inland or when a tsunami – a giant wave usually generated by an oceanic earthquake – hits the shore.

The big question is, can we predict future megafloods? "Not easily," says Gibbard. "We know volcanoes erupt under ice caps in Iceland. People are trying to predict volcanic activity, but we're not there yet."

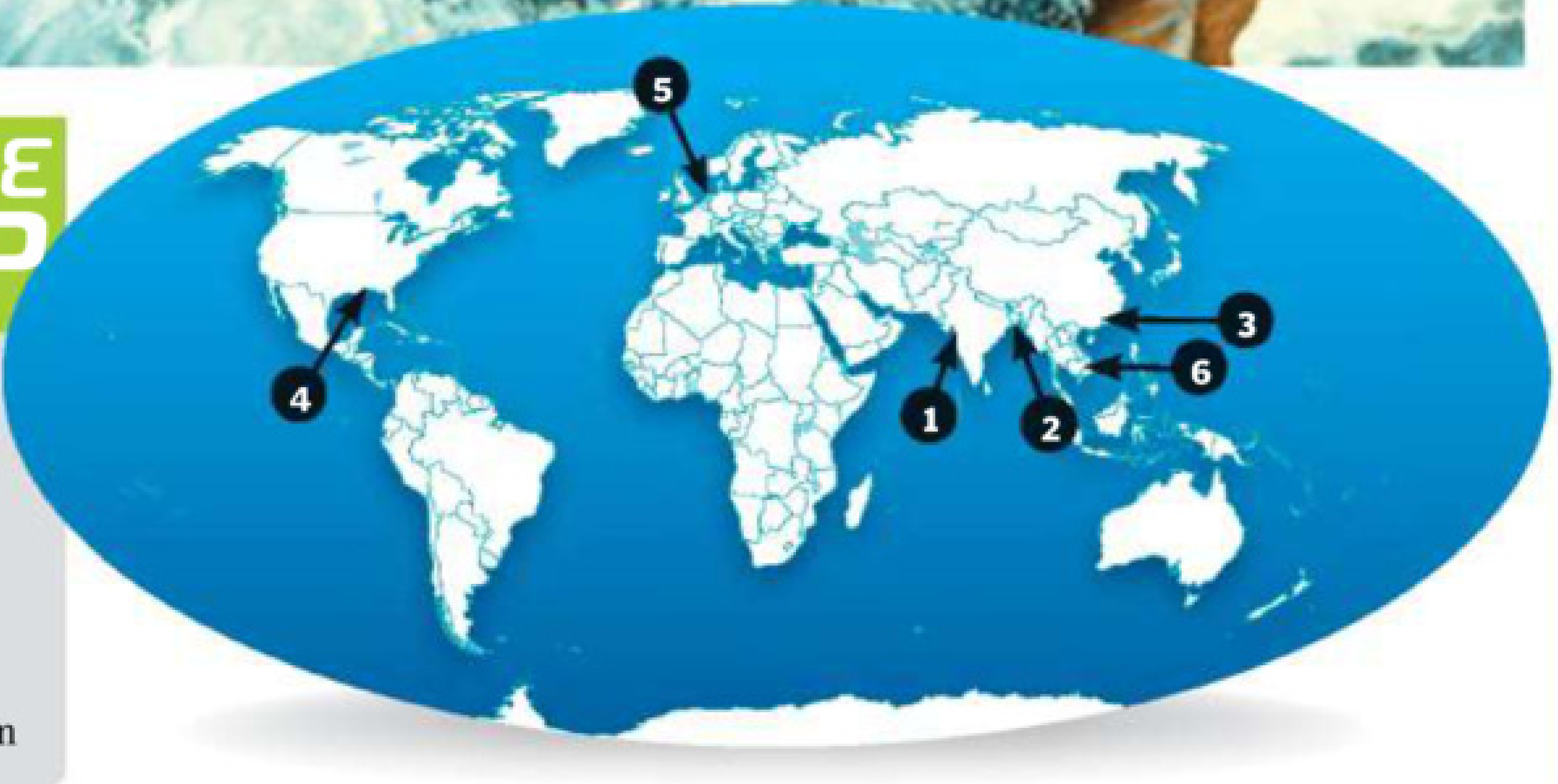
The next 'megaflood' might come from a man-made dam rupturing during an earthquake. Gibbard explains, "Anywhere where water is stored on less-than-firm ground might go. The sheer height of water behind those barrages must be enormous."

It's a real risk. Out of 85,000 American dams, over 4,400 are considered liable to failure. Among them is the Lake Isabella Dam in California. A strong earthquake could send around 700 million cubic metres (2.5 billion cubic feet) of water tumbling downriver. For now though the best we can do is never to underestimate the mighty power of water.



A giant ice dam rupturing under the weight of Lake Missoula is responsible for the megaflood that carved out the Grand Coulee (inset)

ON THE MAP



Flood-prone places around the globe

1 India
2 Bangladesh
3 Guangzhou, China
4 New Orleans, USA
5 The Netherlands
6 Ho Chi Minh City, Vietnam

The Thames Barrier is an engineering marvel, protecting London from high tides

How we defend against floods

An estimated 37 per cent of the world's population live within 100 kilometres (62 miles) of the coast – many in major cities like London, New York and Tokyo. They are at risk of flooding from unusually high tides and storm surges.

Many cities protect themselves from this threat with hi-tech barriers, dams or sluice gates. For example, the Thames Barrier downstream of London is a set of gates that lie flat on the riverbed when open. The gates rotate upright when a storm surge heads inland from the North Sea, or heavy rainfall raises the river level of the Thames enough that normal tides will cause flooding. Each gate can hold back 90,000 tons of water.

Other flood defence systems have permanent dams with sliding sluice gates to control water flow. The Oosterscheldedam in the Netherlands – the largest tidal barrier on Earth – is nine kilometres (5.6 miles) long and has 62 colossal gates; these raise to make the structure watertight.

New Orleans was flooded in Hurricane Katrina in 2005 – one of the deadliest storms in US history. Much of the city lies below sea level and depends on man-made embankments to keep out water. During the hurricane, these levees broke. The US Army is renovating the levees and building new defences, including a pumping station able to pump 540 cubic metres (19,000 cubic feet) of rainwater every second – enough to empty an Olympic-sized swimming pool in five seconds.

© Professor Sanjeev Gupta and Dr Jenny Collier, Department of Earth Science and Engineering, Imperial College London; SPL; Thinkstock; Corbis

Lightning

Capable of breaking down the resistance of air, lightning is a highly visible discharge of electricity capable of great levels of destruction. But how is it formed?

Intense upthrust of volcanic particles can help generate lightning.

Lightning occurs when a region of cloud attains an excess electrical charge, either positive or negative, that is powerful enough to break down the resistance of the surrounding air. This process is typically initiated by a preliminary breakdown within the cloud between its high top region of positive charge, large central region of negative charge and its smaller lower region of positive charge.

The different charges in the cloud are caused when water droplets are supercooled within it to freezing temperatures and then collide with ice crystals. This process causes a slight positive charge to be transferred to the smaller ice crystal particles and a negative one to the larger ice-water mixture, with the former rising to the top on updrafts and the latter falling to the bottom under the effect of gravity. The consequence of this is gradual charge separation between the upper and lower parts of the cloud.

This polarisation of charges forms a channel of partially ionised air – ionised air is that in which neutral atoms and molecules are converted to electrically charged ones – through which an initial lightning stoke (referred to as a 'stepped leader') propagates down through towards the ground. As the stepped leader reaches the Earth, an upwards connecting discharge of the opposing polarity meets it and completes the connection, generating a return stroke that due to the channel now being the path of least resistance, returns up through it to the cloud at one-third the speed of light and creating a large flash.

This leader-return stroke sequence down and up the ionised channel through the air commonly occurs three or four times per strike, faster than the human eye is capable of perceiving. Further, due to the massive potential difference between charge areas – often extending from ten to 100 million volts – the return stroke can hold currents up to 30,000 amperes and reach 30,000°C. Typically the leader stroke reaches the ground in ten milliseconds and

5 TOP FACTS LIGHTNING

Technicolour

1 The super-rare ball lightning can materialise in different colours, ranging from blue through yellow and on to red. It is also typically accompanied by a loud hissing sound.

Zeus

2 The ancient Greeks believed that lightning was the product of the all-powerful deity, weather controller and sky god Zeus. His weapon for smiting was the lightning bolt.

Harvest

3 Since 1980 lightning has been looked at by energy companies as a possible source of energy, with numerous research projects launched to investigate its potential.

Fawksio

4 In 1769 in Brescia, Italy, lightning struck the Church of St Nazaire, igniting 100 tons of gunpowder in its vaults. The explosion killed 3,000 and destroyed a sixth of the city.

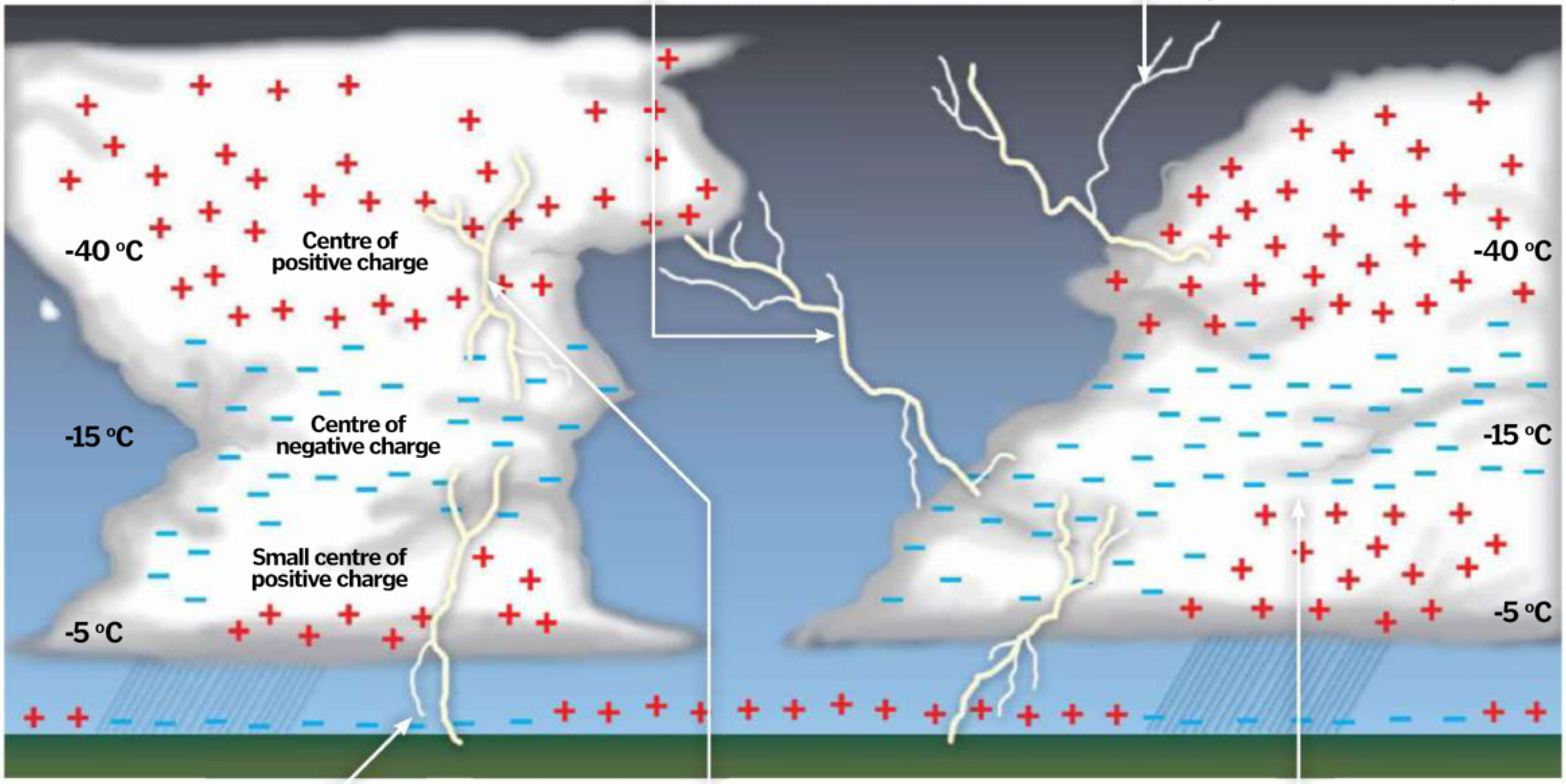
Flashmaster

5 From satellite data, scientists postulate that there are roughly 1.4 billion lightning flashes a year. 75 per cent of these flashes are either cloud-to-cloud or intra-cloud.

DID YOU KNOW? The peak temperature of a lightning bolt's return-stroke channel is 30,000°C

© Science Photo Library

Explaining the formation of lightning


-40 °C
Centre of positive charge
-15 °C
Centre of negative charge
Small centre of positive charge
-5 °C
-40 °C
-15 °C
-5 °C

Cloud-to-cloud
Cloud-to-cloud lightning discharges occur between polarised areas of differing charge, however here the ionised channel runs between clouds instead of a cloud to the ground.

Cloud-to-air
Similar to cloud-to-cloud, cloud-to-air strikes tend to emanate from the top-most area of a cloud that is positively charged, discharging through an ionised channel directly into the air.

Cloud-to-ground
Cloud-to-ground lightning occurs when a channel of partially ionised air is created between areas of positive and negative charges, causing a lightning stroke to propagate downward to the ground.

Intra-cloud
Intra-cloud lightning is the most frequent type worldwide and occurs between areas of differing electrical potential within a single cloud. It is responsible for most aeroplane-related lightning disasters.

Charge differential
Clouds with lightning-generating potential tend to consist of three layers of charge, with the top-most part a centre of positive charge, the middle a centre of negative charge, and the bottom a secondary small centre of positive charge.

the return stroke reaches the instigating cloud in 100 microseconds.

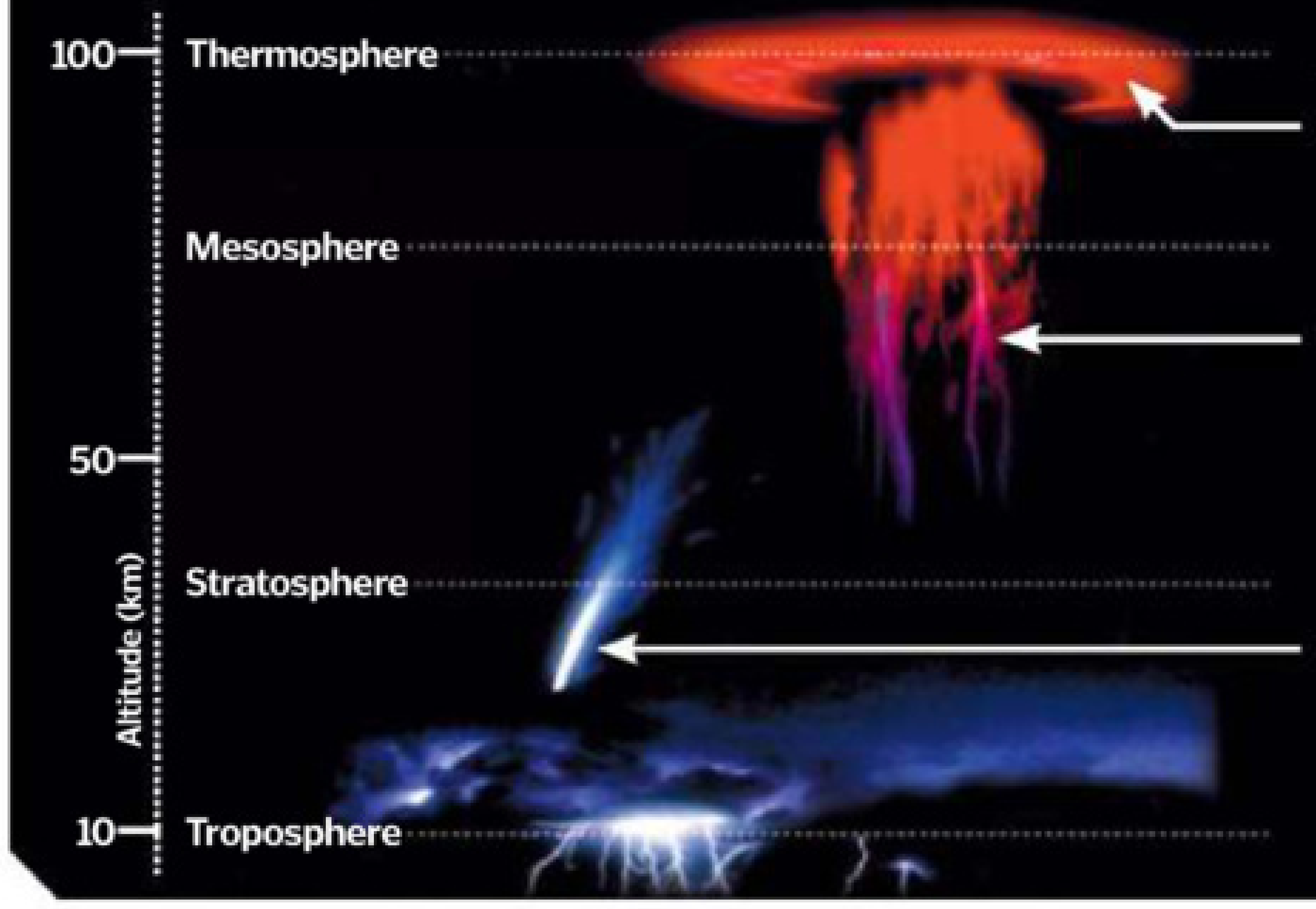
Lightning, however, does not just occur between clouds (typically cumulonimbus or stratiform) and the ground, but also between separate clouds and even intra-cloud. In fact, 75 per cent of all lightning strikes worldwide are cloud-to-cloud or intra-cloud, with discharge channels forming between areas of positive and negative charges between and within them. In addition, much lightning occurs many miles above the Earth in its upper atmosphere (see 'Atmospheric lightning' boxout), ranging from types that emanate from the top of clouds, to those that span hundreds of miles in width.

Interestingly, despite the high frequency of lightning strikes and their large amount of contained energy, current efforts by the scientific community to harvest its power have been fruitless. This is mainly caused by the inability of modern technology to receive and store such a large quantity of energy in such a short period of time, as each strike discharges in mere milliseconds. Other issues preventing lightning's use as an energy source include its sporadic nature – which while perfectly capable of striking the same place twice, rarely does – and the difficulties involved in converting high-voltage electrical power delivered by a strike into low-voltage power that can be stored and used commercially.

> "Due to the massive potential difference between charge areas the return stroke can hold currents up to 30,000 amperes and reach 30,000°C"

Atmospheric lightning

Unseen apart from by satellites, a major part of the world's annual lightning is generated in Earth's upper atmosphere.



Elves
Vast 250-mile wide flattened discs of light, elves occur above low-lying thunderstorms. They are caused by the excitation of nitrogen molecules due to electron collisions in the atmosphere.

Sprites
Sprites are caused by the discharges of positive lightning from thunderclouds to the ground. They vary in colour from red to blue and appear akin to large jellyfish.

Blue jets
Emanating from the top of cumulonimbus clouds and stretching in a cone shape up into the stratosphere and mesosphere, blue jets are caused by intense hail activity within a storm.

Lightning types

Far from uniform, lightning is an unpredictable phenomenon

Bead lightning

A type of cloud-to-ground lightning where the strike seems to break up into smaller, super-bright sections (the beads), lasting longer than a standard discharge channel.

Frequency: **Rare**

Ribbon lightning

Only occurring in storms with high cross winds and multiple return strokes, ribbon lightning occurs when each subsequent stroke is blown to the side of the last, causing a visual ribbon effect.

Frequency: **Quite rare**

Staccato lightning

A heavily branched cloud-to-ground lightning strike with short duration stroke and incredibly bright flash.

© Scotto Bear

Frequency: **Common**

Sheet lightning

A generic term used to describe types of cloud-to-cloud lightning where the discharge path of the strike is hidden from view, causing a diffuse brightening of the surrounding clouds in a sheet of light.

© Christian Artntzen

Frequency: **Common**

Megalightning

A term commonly used when referring to upper-atmospheric types of lightning. These include sprites, blue jets and elves (see 'Atmospheric lightning' boxout) and occur in the stratosphere, mesosphere and thermosphere.

Frequency: **Frequent**

Ball lightning

Considered as purely hypothetical by meteorologists, ball lightning is a highly luminous, spherical discharge that according to few eyewitnesses last multiple seconds and can move on the wind.

Frequency: **Very rare**

Lightning hotspots

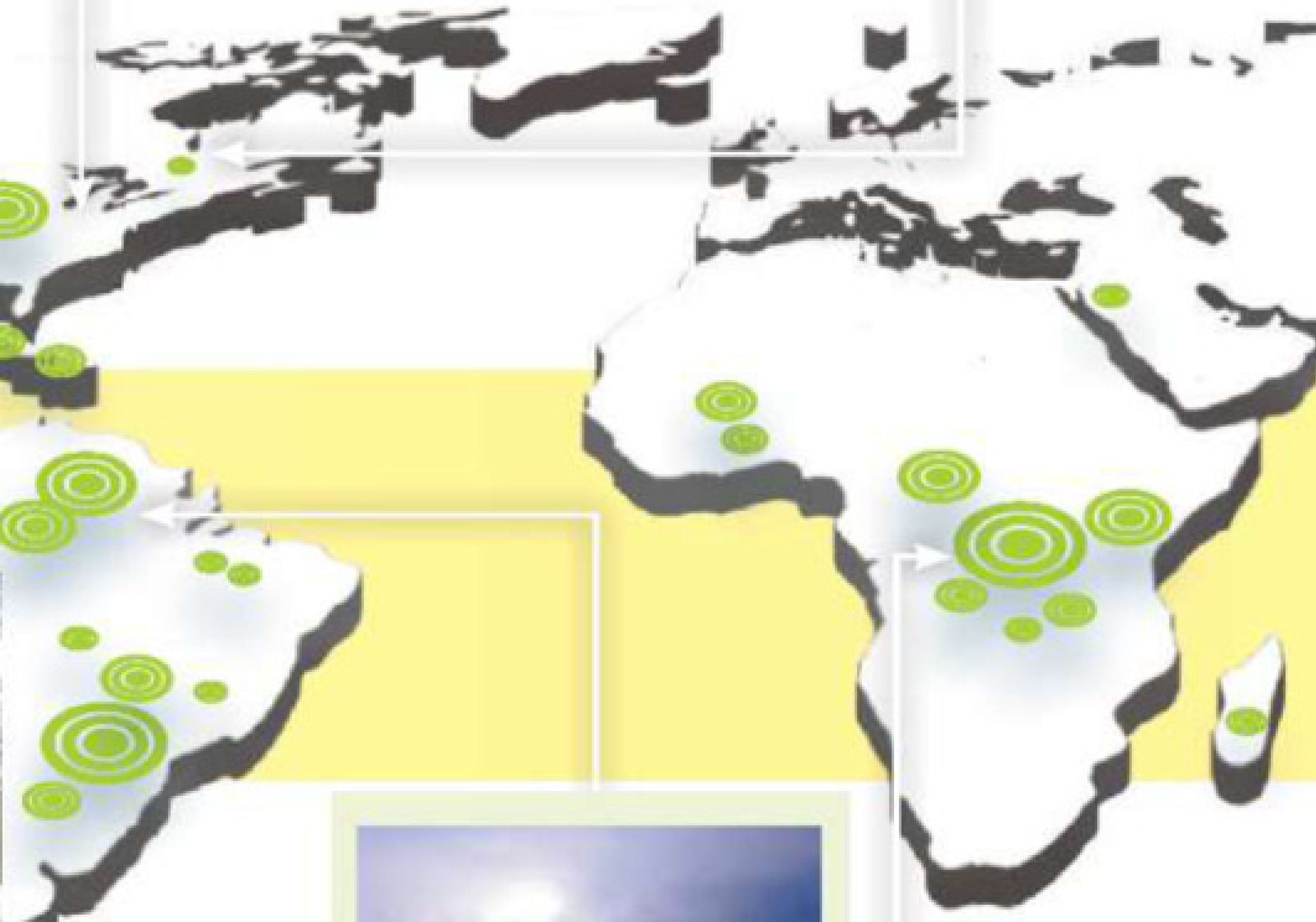
A look at some of the most dangerous places to be when lightning strikes

Multiple strikes

The Empire State Building is struck 24 times per year on average. It was once struck eight times in 24 minutes.

Danger zone

Ten per cent of all people struck by lightning were in Florida at the time.



70% OF GLOBAL LIGHTNING OCCURS IN THE TROPICS

© Ggoodwyn

'Damn! And to think that tree was just two months from retirement'

Flashes

Above the Catatumbo River in Venezuela lightning flashes several times per minute 160 nights of the year.

Global hotspot

The small village of Kifuka is the most struck place on Earth, with 158 strikes per square kilometre per year.

What are the chances?

The odds of being hit by lightning aren't as slim as you think…

1 in 3,000,000

The chance of you getting struck by lightning is one in 3 million. Which, while seeming quite unlikely, did not stop US park ranger Roy Sullivan from being struck a world record seven times during his lifetime.

HEAD 2 HEAD LIGHTNING IN FILMS

MOST CLASSICAL

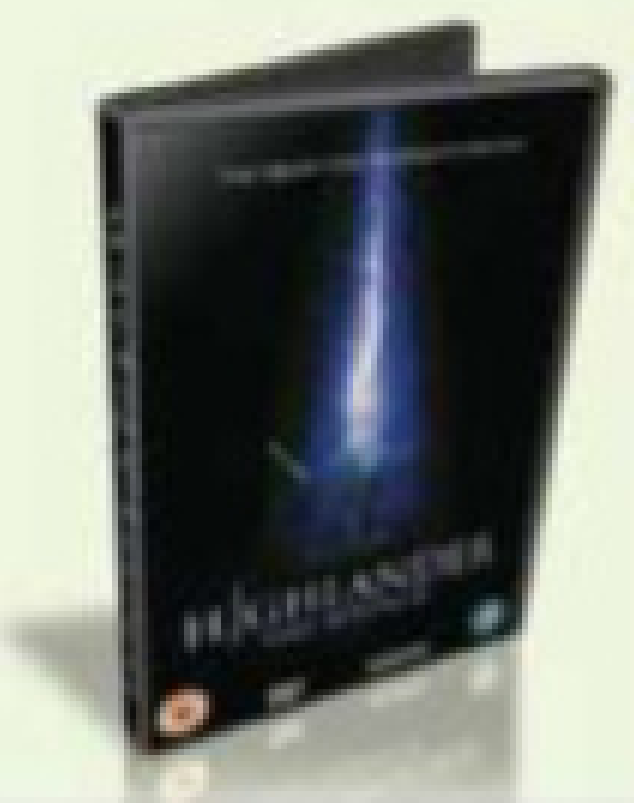
1. Percy Jackson & The Lightning Thief

A film in which Percy 'Perseus' Jackson, son of Poseidon, must fight mythological beasts and travel to Hades to retrieve Zeus' stolen lightning bolt in order to prevent a war.

MOST FUTURISTIC

2. Back To The Future

Protagonist Marty McFly travels back in time in Doc Brown's time travelling, lightning-inducing DeLorean, in order to ensure his parents hook-up and guarantee his own existence.



MOST IMMORTAL

3. Highlander

An immortal Scottish swordsman must confront his last two rivals in order to win the fabled 'Prize'. Of course, each time a foe is vanquished his power is absorbed in a lightning strike.

DID YOU KNOW? *The irrational fear of lightning is referred to as astraphobia*

Cloud-to-cloud lightning streaks across the Masai Mara Game Reserve in Kenya, Africa

© Science Photo Library

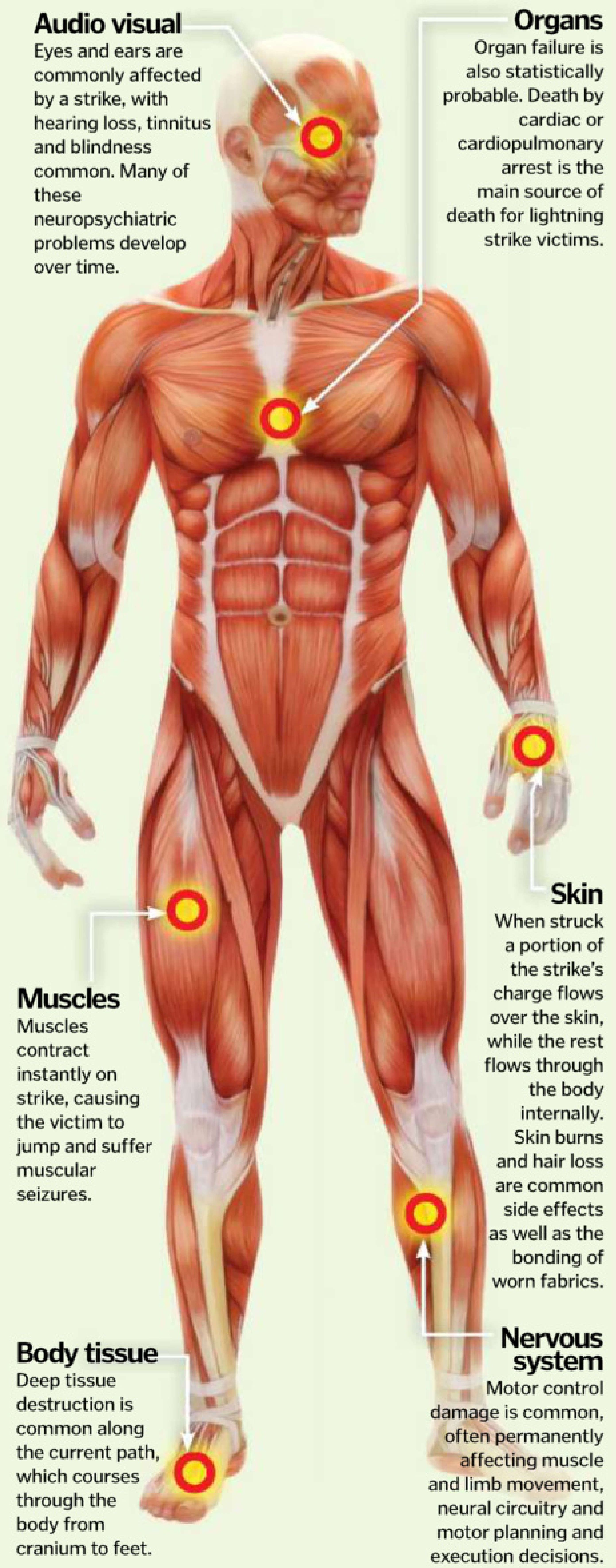
What happens when you get struck by lightning?

The parts of the body that feel the effect if struck by lightning

When a human is hit by lightning, part of the strike's charge flows over the skin – referred to as external flashover – and part of it goes through them internally. The more of the strike that flows through, the more internal damage it causes. The most common organ affected is the heart, with the majority of people who die from a strike doing so from cardiac arrest. Deep tissue destruction along the current path can also occur, most notably at the entrance and exit points of the strike on the body. Lightning also causes its victims to physically jump, which is caused by the charge contracting the muscles in the body instantaneously.

Burns are the most visible effect of being struck by lightning, with the electrical charge heating up any objects in contact with the skin to incredible levels, causing them to melt and bond with the human's skin. Interestingly, however, unlike industrial electrical shocks – which can last hundreds of milliseconds and tend to cause widespread burns over the body – lightning-induced burns tend to be centred more around the point of contact, with a victim's head, neck and shoulders most affected.

Post-strike side-effects of being struck by lightning range from amnesia, seizures, motor control damage, hearing loss and tinnitus, through blindness, sleep disorders, headaches, confusion, tingling and numbness. Further, these symptoms do not always develop instantaneously, with many – notably neuropsychiatric problems (vision and hearing) – developing over time.



Audio visual
Eyes and ears are commonly affected by a strike, with hearing loss, tinnitus and blindness common. Many of these neuropsychiatric problems develop over time.

Organs
Organ failure is also statistically probable. Death by cardiac or cardiopulmonary arrest is the main source of death for lightning strike victims.

Skin
When struck a portion of the strike's charge flows over the skin, while the rest flows through the body internally. Skin burns and hair loss are common side effects as well as the bonding of worn fabrics.

Muscles
Muscles contract instantly on strike, causing the victim to jump and suffer muscular seizures.

Body tissue
Deep tissue destruction is common along the current path, which courses through the body from cranium to feet.

Nervous system
Motor control damage is common, often permanently affecting muscle and limb movement, neural circuitry and motor planning and execution decisions.

© Science Photo Library

Deadly
In July 2007, 30 people were killed by lightning in the remote village of Ushari Dara in northwestern Pakistan.

Singapore strikes!
Singapore has one of the world's highest rates of lightning activity.

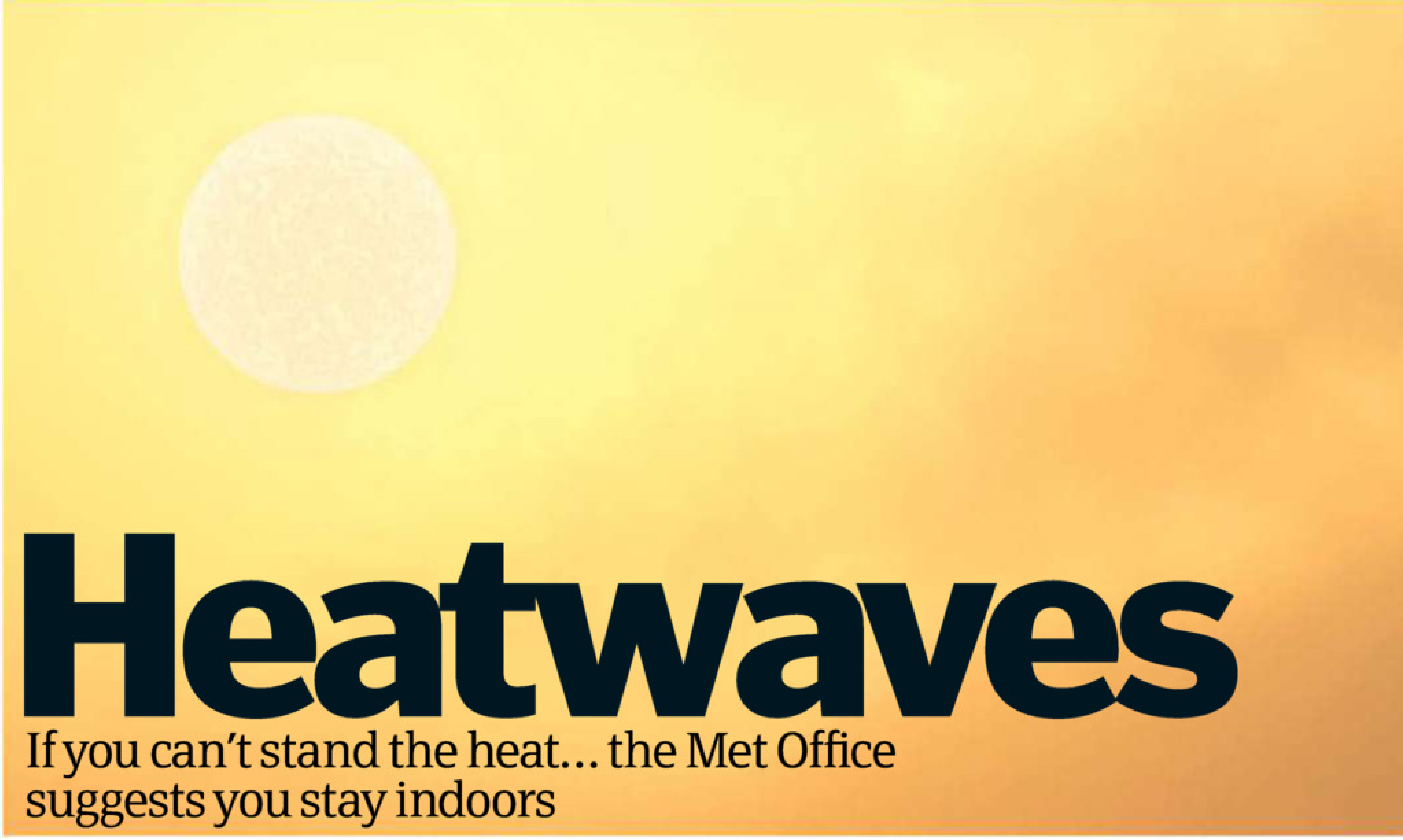
in comparison...

1 in 14,000,000
The chance of winning the lottery in the UK is one in 14 million. That is over four and a half times as unlikely as being struck.

1 in 11,000,000
Flying on a single-trip commercial air flight inflicts you to a one in 11 million chance of being killed in an accident.

1 in 12,000,000
The odds of getting hit by lightning likelier when in the UK the chance of dying from Mad Cow Disease is one in 12 million.

1 in 8,000
In order to get better odds, go out in your car. Over 3,000 people are killed every day on roads worldwide.



Heatwaves

If you can't stand the heat… the Met Office suggests you stay indoors

Although, according to Met Office meteorologist John Hammond, there's no official definition of a heatwave, these hot-weather phenomena take their toll not only on a population's health, but also business and infrastructure – such as power, water and transport. A heatwave is a period of unusually hot or humid weather that lasts at least two or three days – and remaining hot throughout the nights – that affects large areas. Heatwaves are caused by a system of higher atmospheric pressure, whereby air from upper levels of the atmosphere descends and rotates out. As it descends, it compresses, increasing the temperature. The outward flow, meanwhile, makes it difficult for other systems to enter the area, and the large size and slow speed of the hot air causes the heatwave to remain for days or even weeks. The lack of clouds means that an affected area is struck with strong sunlight.

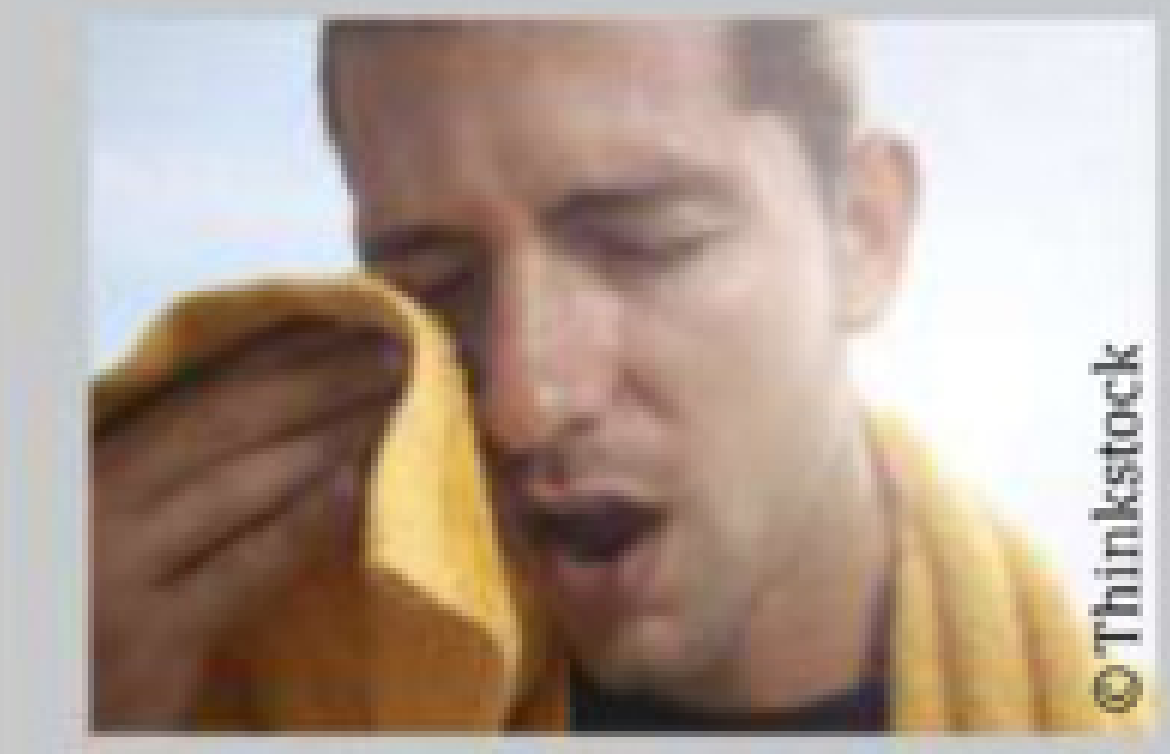
Hammond reveals that the hottest temperatures in the UK are likely to be over parts of central and southern England, away from immediate coastal areas, which are cooled by sea breezes. "Temperatures have exceeded 30°C in the UK," he explains, "[but around] Europe and the world, weather conditions can bring temperatures exceeding 40°C. This has happened in Mediterranean regions, the Middle East and Australia among other areas."

Heatwaves are relative to an area's climate – temperatures that would constitute a heatwave in one area might not in another location – and the health effects on the individual are also relative to a range of risk factors. People adapt and become accustomed to their long-term temperature patterns, making a heatwave a relative experience.

The Met Office Heat Health Watch is a warning system that issues alerts – levels 1-4 – if a heatwave is imminent. "[We] can identify weather patterns that might bring hot temperatures to the UK several days in advance," explains Hammond. "When high temperatures are expected, detailed advice will go to the relevant health organisations, so they can inform people affected by the heat. Met Office forecasts on TV, radio, newspapers and online will also provide temperature forecasts for the public."

TYPES OF… HEATWAVE

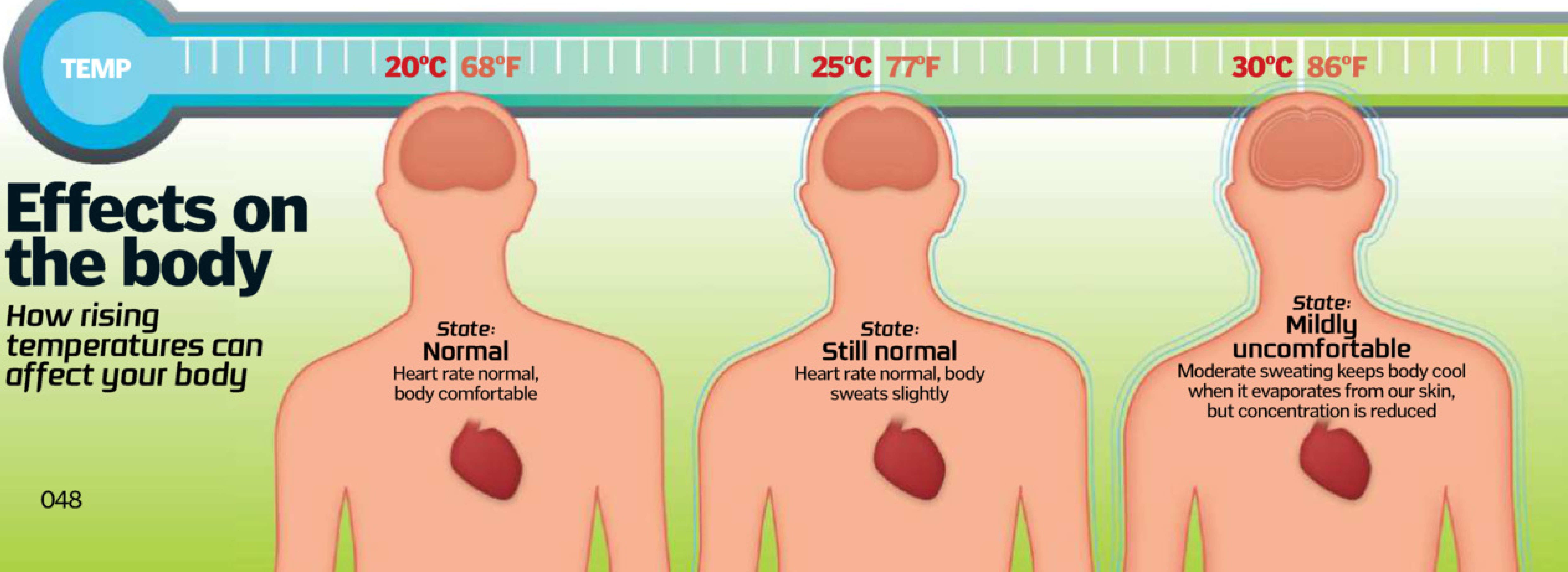
1 Dry heatwaves
Occurring in continental or Mediterranean regions, dry heatwaves are linked to clear skies and high solar radiation, as well as windy conditions, which can increase stress at excessive heat levels.



© Thinkstock

2 Moist heatwaves
Moist heatwaves bring hot and humid conditions during the day with nighttime cloud that prevents heat from escaping. These muggy heatwaves are mostly found in mid-latitude temperate and maritime regions.

3 Heat island effect
Large urban areas can experience a kind of microclimate known as the heat island effect. Here, conditions during a heatwave tend to be worse because the Sun's heat is stored in the tarmac of roads and cement of buildings and is unable to escape until the night.



Effects on the body

How rising temperatures can affect your body

State: **Normal**
Heart rate normal, body comfortable

State: **Still normal**
Heart rate normal, body sweats slightly

State: **Mildly uncomfortable**
Moderate sweating keeps body cool when it evaporates from our skin, but concentration is reduced

5 TOP FACTS HEATWAVES

Power outage

1 Heatwaves threaten resources due to increased water and electricity consumption. For example, power outages have been known to occur due to increased use of air conditioning.

Hyperthermia

2 Unlike hypothermia (core temperature drop), hyperthermia is a condition caused by heat stroke whereby you absorb more heat than can dissipate.

Hottest recorded temp

3 John Hammond informed us that the highest recorded temperature in the world was a whopping 58°C in Libya back on 13 September 1922. Scorchio!

Sunny side up

4 The Met Office records show that in terms of average annual sunshine, the sunniest place on the planet is Yuma, Arizona, which enjoys 4,300 hours each year.

Meltdown

5 Roads melted in England in July 2006 when temperatures reached 37°C (official heatwave conditions as the average max temp for that week is usually 21-23°C).

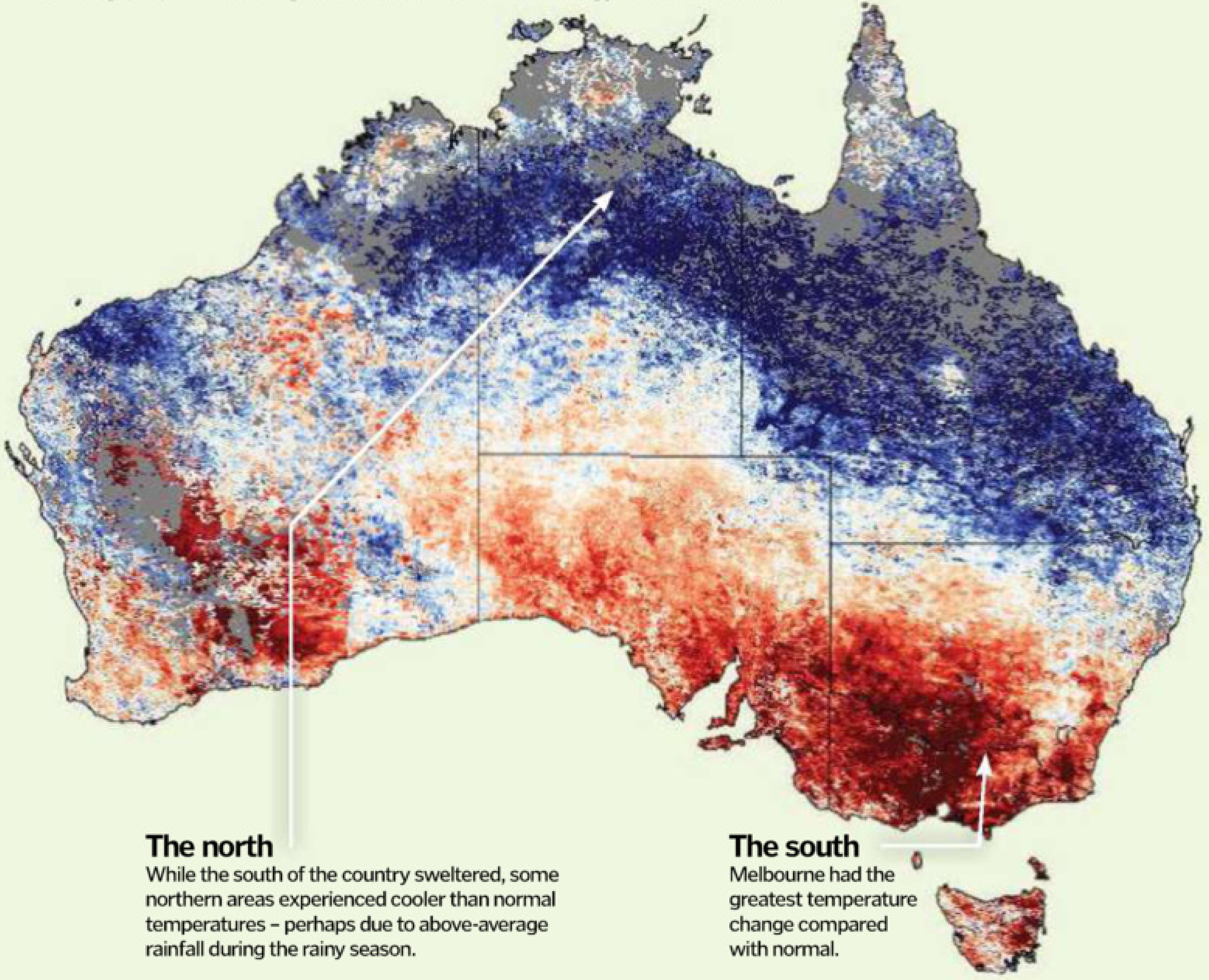
DID YOU KNOW? *In the UK's heatwave of 1967, penguins from Chessington Zoo went to the local ice rink to cool off*

Australia heatwave breaks records

This map of Australia captured by NASA's Moderate-Resolution Imaging Spectroradiometer (MODIS) compares January-February 2009's average land temperature with previous years. Red areas are warmer than previously while blue areas are cooler. The darker the colour the more extreme the temperature change. Really dark red or dark blue areas reveal where the difference in temperature is 10°C higher or lower than previously.

The abnormally hot temperatures here – the highest recorded being 48.8°C in Hopetoun, Victoria – indicate a severe heatwave. Slow-moving high pressure lingered over the Tasman Sea and conditions conspired to cause hot tropical air to blow across south-east Australia. The extreme heat worsened the country's already-dangerous bushfire season, and led to the Black Saturday bushfires, which caused the deaths of 173 people on Saturday 7 February, also destroying homes and towns in the process.

South-east Australia's January heatwave set the record for Melbourne's highest recorded temperature of a blistering 46.4°C according to the Bureau of Meteorology in Melbourne.



The north
While the south of the country sweltered, some northern areas experienced cooler than normal temperatures – perhaps due to above-average rainfall during the rainy season.

The south
Melbourne had the greatest temperature change compared with normal.

© NASA

Interview

For advice on heat health, we spoke to the Met Office's Patrick Sachon, Health Service Development Manager

How It Works: At what temperature does the body begin to notice negative effects from heat?

Patrick Sachon: The effects of heat on people's health in the UK starts at relatively modest temperatures. Epidemiological studies have shown that maximum air temperatures of only 23-24°C are associated with excess summer mortality. Physiologically, when the ambient temperature is higher than the skin temperature, the body has to regulate its temperature by losing heat through sweating. At this stage if any other factor reduces the body's effectiveness of sweating – such as dehydration, close fitting clothing or taking certain medications – it can cause the body to overheat. Acclimatisation and adaptation play an important part in how well people can tolerate different levels of heat. This is why people in somewhere like Madrid are more accustomed to higher temperatures than people in London.

HIW: What is the highest temperature a human body can tolerate?

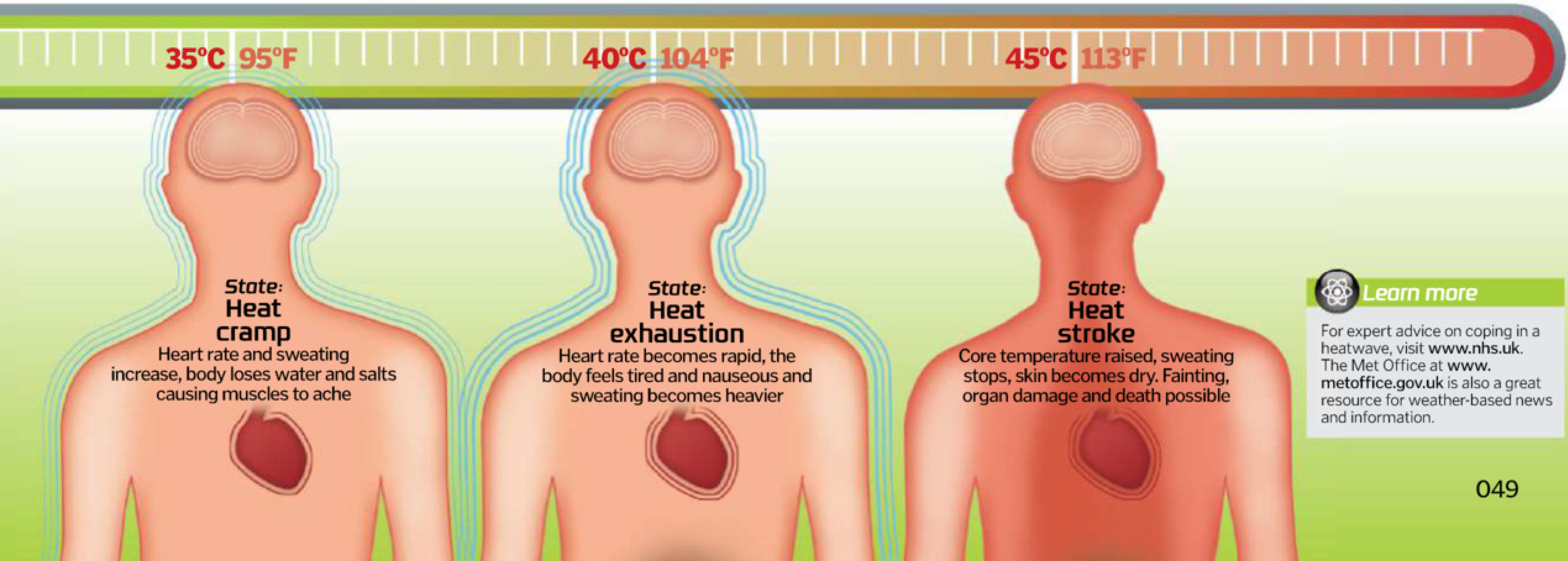
PS: There are currently no studies that we are aware of that have identified a maximum temperature. As I say, acclimatisation and adaptation have an important part to play in how well people can tolerate different levels of heat. In England, relatively modest maximum temperatures are associated with excess mortality.

HIW: Why does heat make us dehydrated?

PS: In order to lose heat we need to sweat, this leads to fluid loss. If we do not replace this fluid we can become dehydrated. One of the most important things to do in hot weather is to drink sufficient fluids, such as water or fruit juices.

HIW: How do people living in much hotter countries than the UK cope with/grow accustomed to excessive the heat in the long term?

PS: Their bodies are more acclimatised to the heat and their way of living – the clothes they wear, the houses they live in and the way they live their lives – are more adapted to hot weather.



State: **Heat cramp**
Heart rate and sweating increase, body loses water and salts causing muscles to ache

State: **Heat exhaustion**
Heart rate becomes rapid, the body feels tired and nauseous and sweating becomes heavier

State: **Heat stroke**
Core temperature raised, sweating stops, skin becomes dry. Fainting, organ damage and death possible

Learn more

For expert advice on coping in a heatwave, visit **www.nhs.uk**. The Met Office at **www.metoffice.gov.uk** is also a great resource for weather-based news and information.

Rise of the Superstorm

The science behind tornadoes with the power to devastate cities

Every year around 1,200 tornadoes touch down in the USA. Most occur in a region nicknamed Tornado Alley, with Texas, Oklahoma and Kansas at its core.

The most destructive of 2013 was the Moore Tornado, which touched down at 2.56pm CDT on 20 May, near Newcastle, OK. It was on the ground for 40 minutes and drew a 27-kilometre (17-mile) path through the state, 2.1 kilometres (1.3 miles) across at its widest point. Wind speeds were in excess of 322 kilometres (200 miles) per hour, placing the tornado in the highest category on the Enhanced Fujita (EF) Scale: EF5. Tornadoes of this class cause near-total devastation, levelling multistorey buildings, tearing homes from their very foundations and lifting asphalt from the roads.

North America has unique geography, which provides a deadly spawning ground for storms and tornadoes. The Rocky Mountains extend from north to south along the west side of the continent. As wind travels over the Rockies, it becomes cold and loses moisture via rain and snow, producing cool, dry air at high altitudes. When this air hits warm, humid air from the Gulf of Mexico water vapour condenses and forms storm clouds. This releases huge amounts of energy, causing atmospheric instability.

On 20 May 2013, severe weather warnings were issued for Oklahoma; a polar jet stream came over the Rockies into the southern Great Plains, and simultaneously a low-pressure system moved over the Upper Midwest region. Differences in wind speed at different altitudes – known as wind shear – caused the air to spin, circulating in a horizontal vortex, and in combination with moisture and atmospheric instability. At 2pm CDT, this led to the development of a thunderstorm containing persistent, rotating mesocyclones.

Mesocyclones powerful enough to generate tornadoes often result in hailstorms.

5 TOP FACTS
TORNADO MYTHS

Overpasses are safe
1 It may seem a good shelter, but highway overpasses act like wind tunnels and increase the speed of the air. If you are stuck in your car in a tornado, get out, find a ditch and stay low.

Open windows
2 Despite a myth that opening a building's windows will alleviate wind pressure, it just lets wind and debris in, and chances are, the glass will smash anyway when the storm hits.

Stand in the north
3 Tornadoes often come from the south, but standing in the north of the house won't protect you from debris. Pick a room in the centre on the ground floor, away from any windows.

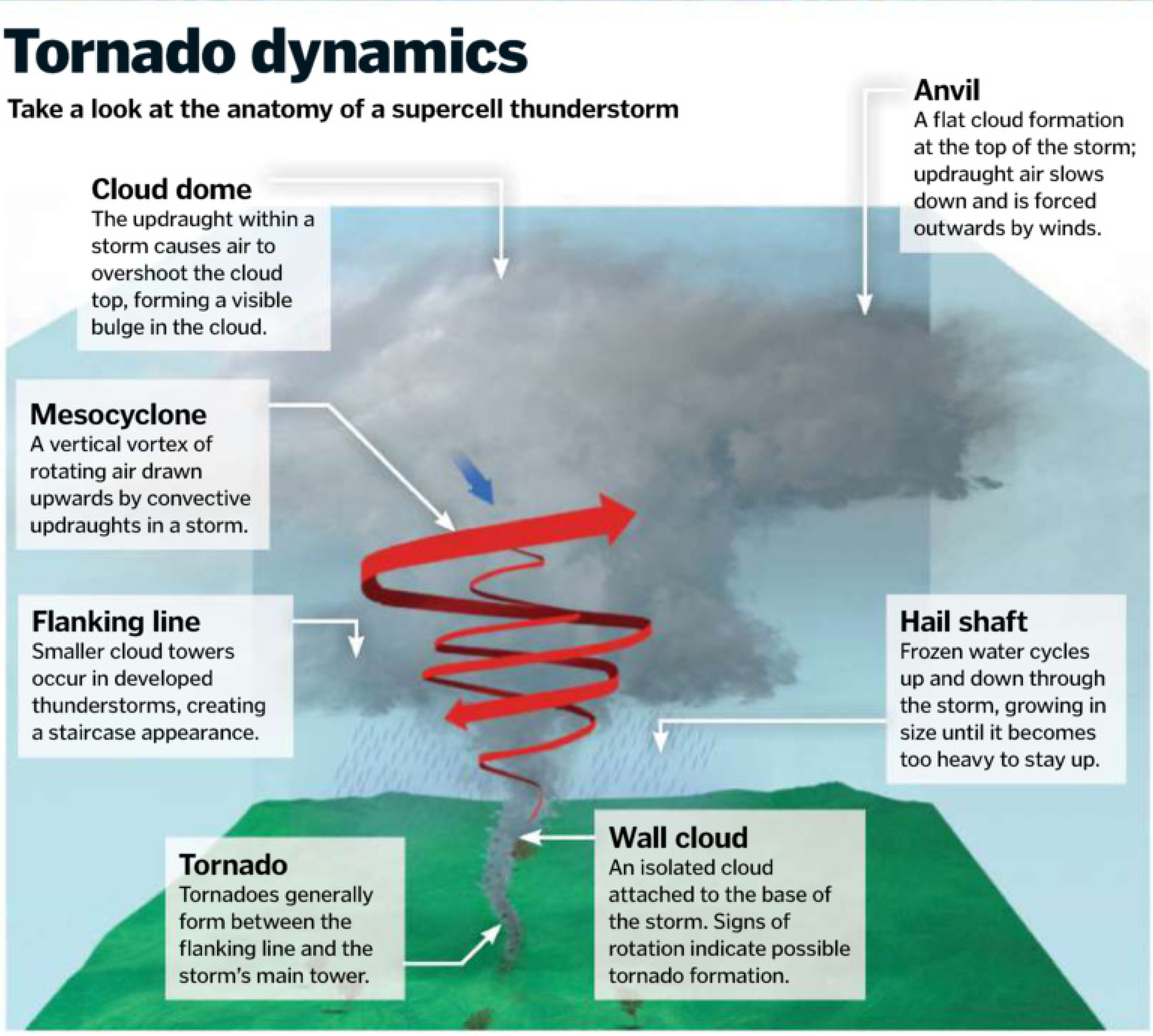
Outdrive the storm
4 The roads will be congested and covered in debris, and a tornado can quickly change direction without warning. Even weak twisters can lift small cars – so don't drive!

Trailers are targeted
5 Trailer parks are much more likely to be damaged by a tornado, but this is due to differences in the quality of construction rather than any natural bias to these abodes.

DID YOU KNOW? Most tornadoes travel from south-west to north-east and occur between 3pm and 9pm

Tornado dynamics

Take a look at the anatomy of a supercell thunderstorm



Cloud dome
The updraught within a storm causes air to overshoot the cloud top, forming a visible bulge in the cloud.

Anvil
A flat cloud formation at the top of the storm; updraught air slows down and is forced outwards by winds.

Mesocyclone
A vertical vortex of rotating air drawn upwards by convective updraughts in a storm.

Flanking line
Smaller cloud towers occur in developed thunderstorms, creating a staircase appearance.

Hail shaft
Frozen water cycles up and down through the storm, growing in size until it becomes too heavy to stay up.

Tornado
Tornadoes generally form between the flanking line and the storm's main tower.

Wall cloud
An isolated cloud attached to the base of the storm. Signs of rotation indicate possible tornado formation.

Updraughts of warm air carry water droplets high into the atmosphere, where they freeze before being carried downwards by cold downdraughts. If they become caught in an updraught again they will refreeze, adding a new layer of ice. This process can repeat several times, generating hailstones that are the size of golf balls or even larger. Oklahoma was pelted with hail as the storm intensified.

If there is sufficient updraught to tighten the central vortex of a mesocyclone it begins to twist, resulting in a powerful vertical column. The inward and outward airflows cause a drop in pressure at the centre, and form what is known as a dynamic pipe. At the core of the vortex, the pressure is lowered, which sucks in more air, causing the column to lengthen and extend down towards the ground.

A tornado warning was issued in Oklahoma at 2.40pm, and the tornado that ravaged Moore touched down 16 minutes later. It started out as a weak EF0 twister, capable of only minor damage to roof shingles, trees and guttering, but within ten minutes it had intensified to EF4. EF4 tornadoes have extremely destructive winds of up to 322 kilometres (200 miles) per hour and, on its path to the city of Moore, it severely damaged a bridge and killed nearly 100 horses at the Orr Family Farm.

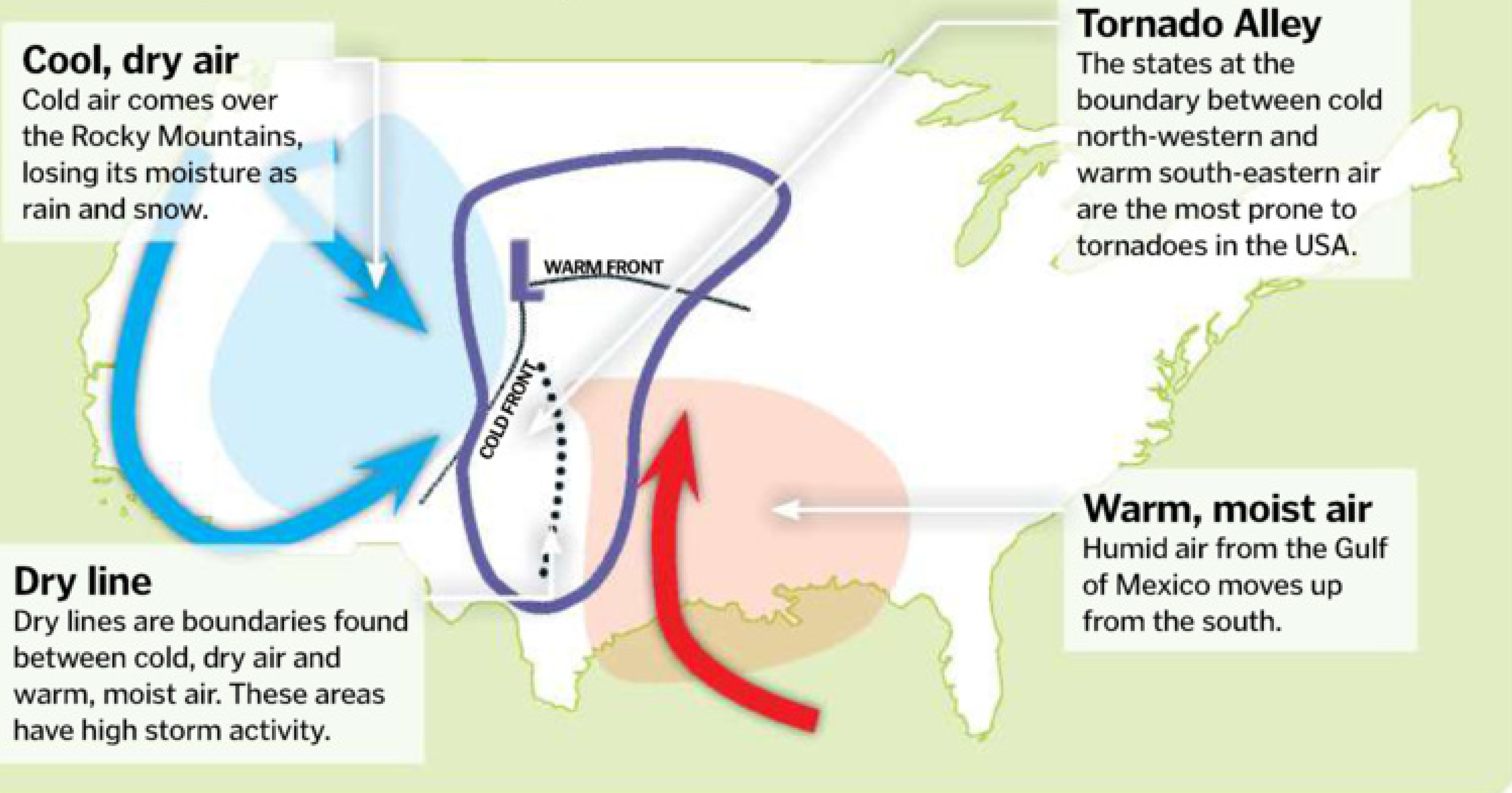
Once in the city, the storm intensified to EF5 – the highest rating for a tornado – and reduced many buildings to rubble. It lost its peak strength and returned to EF4 classification, but the intensity of the storm caused a great deal of damage: 13,500 homes were destroyed, or damaged, affecting 33,000 people, 24 people were killed and hundreds more injured.

The tornado continued to weaken until it eventually dissipated at 3.35pm, about eight kilometres (five miles) east of Moore.

A pickup truck wrapped around a tree trunk during the Moore Tornado

Geography made for disaster

Find out why North America is so prone to twisters



Cool, dry air
Cold air comes over the Rocky Mountains, losing its moisture as rain and snow.

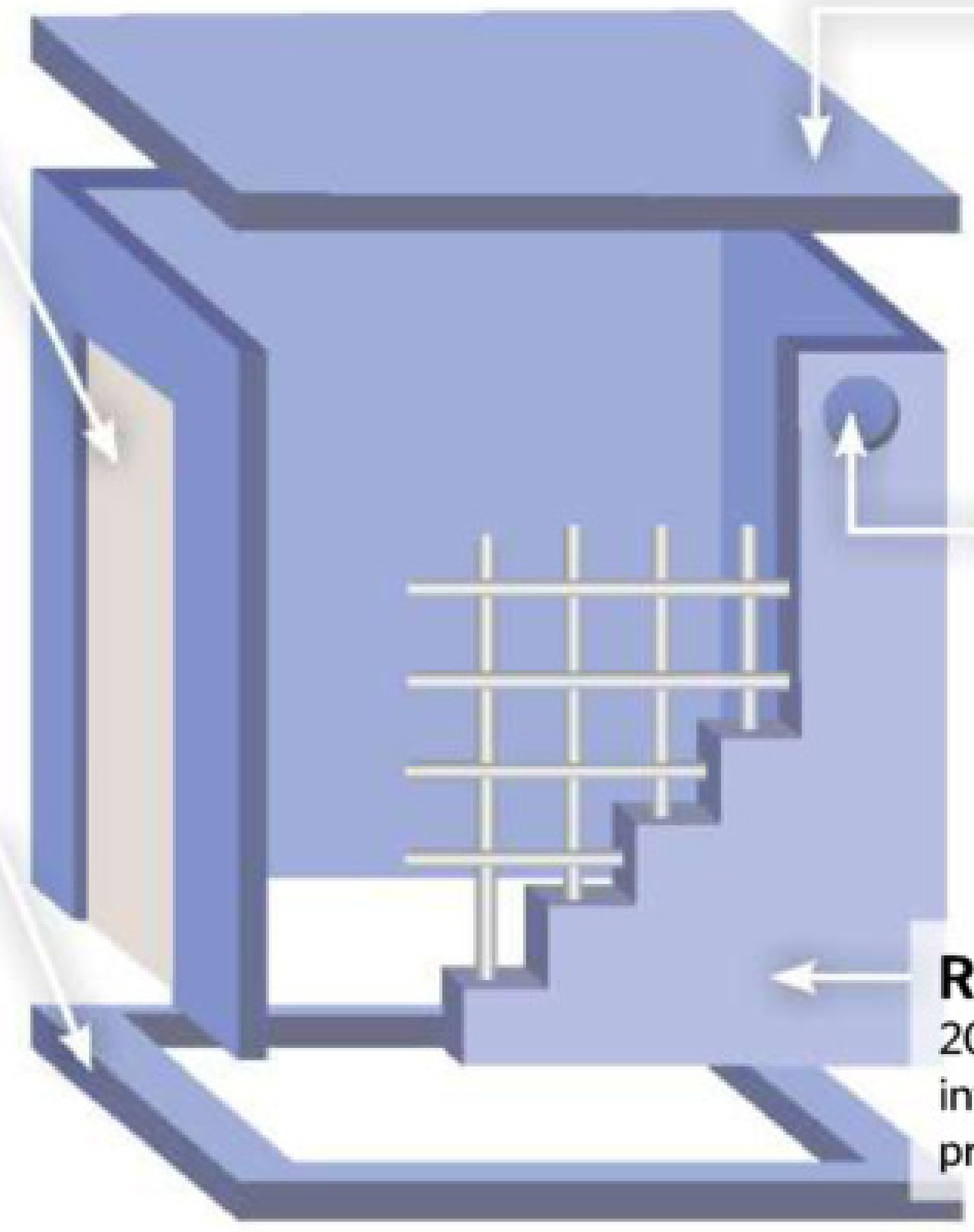
Tornado Alley
The states at the boundary between cold north-western and warm south-eastern air are the most prone to tornadoes in the USA.

Dry line
Dry lines are boundaries found between cold, dry air and warm, moist air. These areas have high storm activity.

Warm, moist air
Humid air from the Gulf of Mexico moves up from the south.

Key features of a storm shelter

What protection do overground storm shelters offer from extreme winds?



Steel and plywood door
Plywood can absorb impacts, while steel prevents shrapnel from penetrating the shelter.

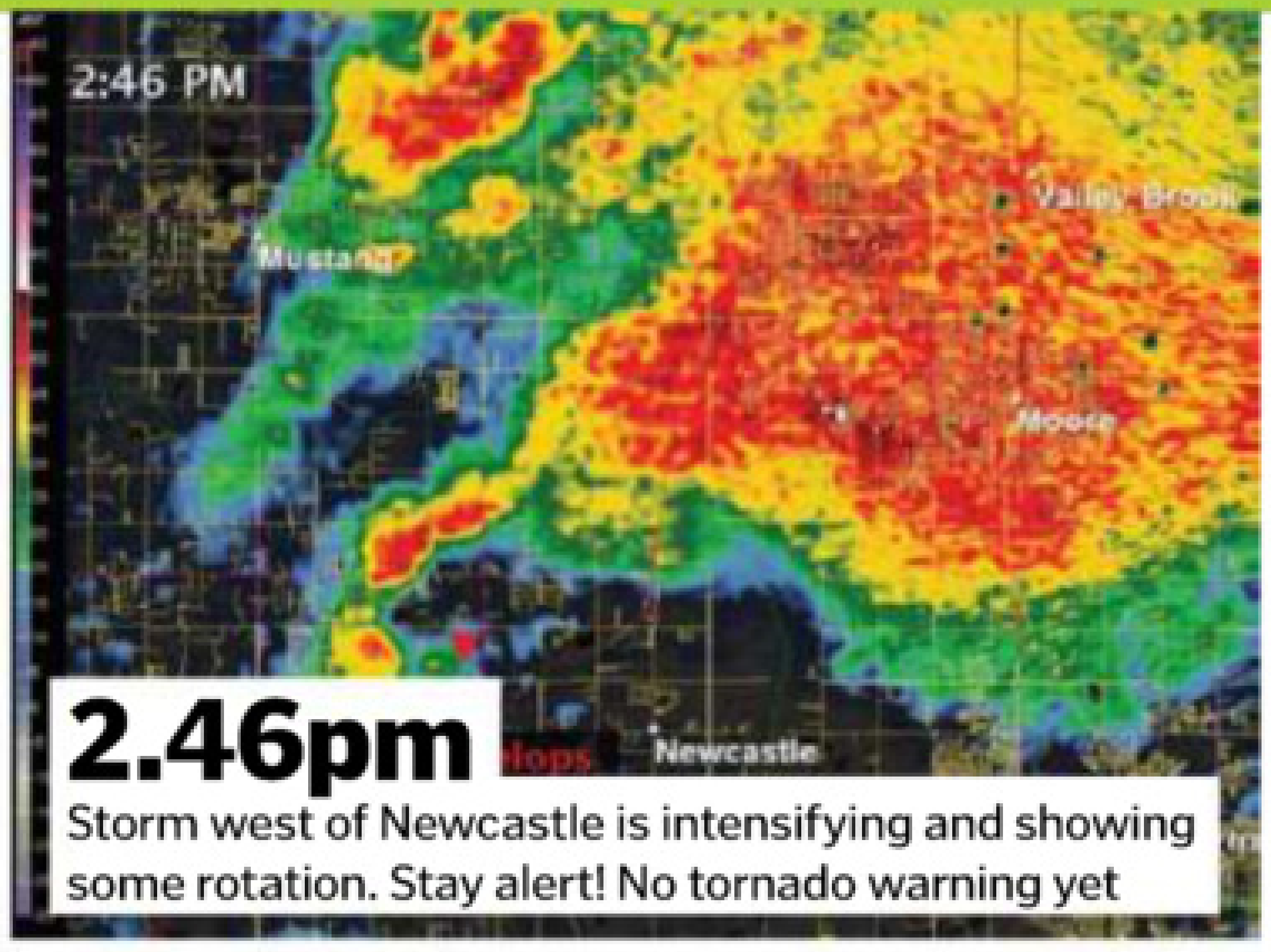
Concrete roof
A 10-15cm (4-6in)-thick concrete roof resists the winds that pull other roofing materials away.

Air vent
Small ventilation holes allow people to breathe without letting any debris into the shelter.

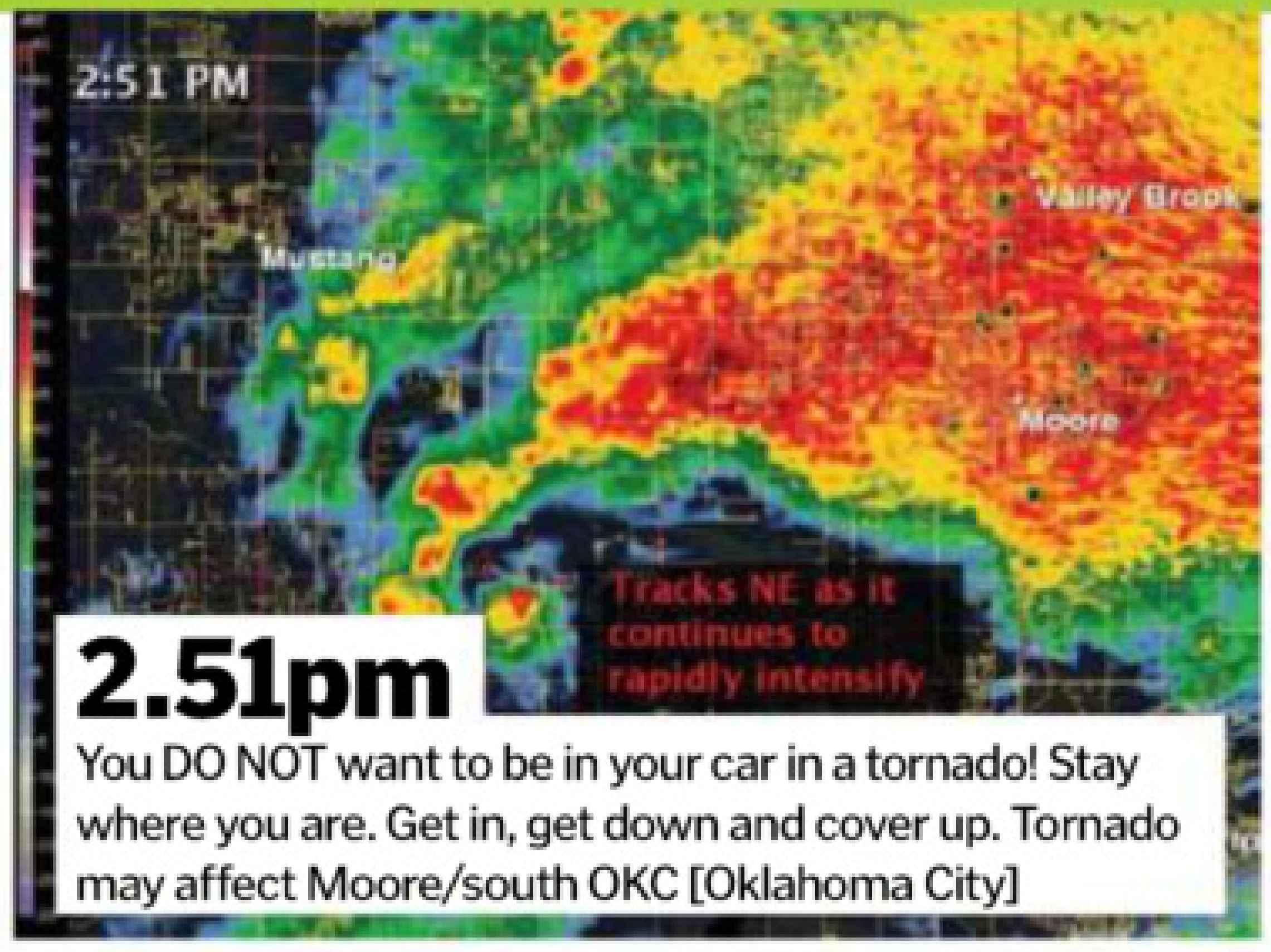
Anchorage
Shelters are anchored to a concrete slab to prevent them from overturning in the wind or being swept away by floodwaters.

Reinforced walls
20cm (8in)-thick concrete walls with internal steel grid supports provide protection from wind and debris.

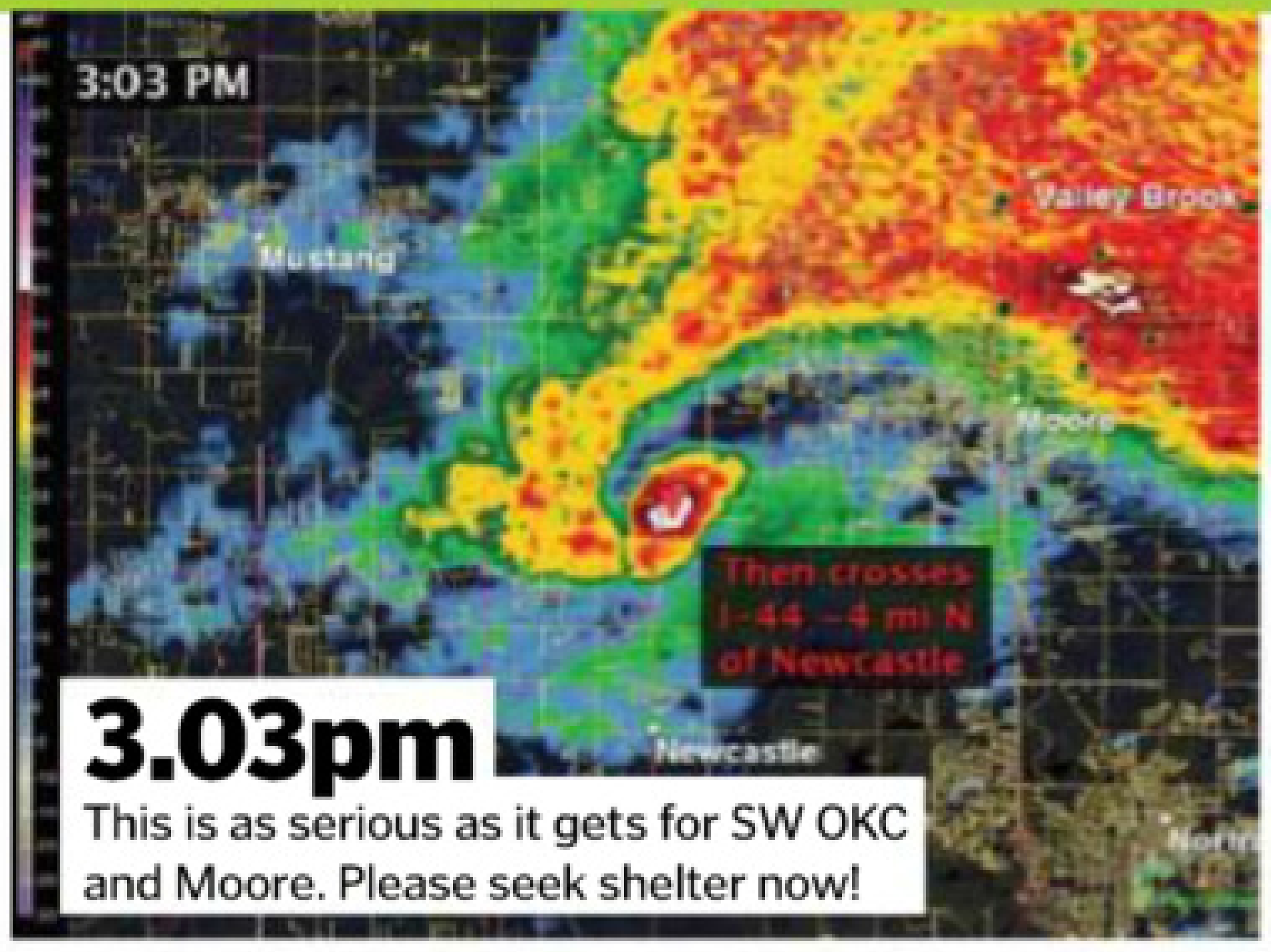
Timeline of the Moore Tornado Live tweets from NWS Norman



2.46pm
Storm west of Newcastle is intensifying and showing some rotation. Stay alert! No tornado warning yet



2.51pm
You DO NOT want to be in your car in a tornado! Stay where you are. Get in, get down and cover up. Tornado may affect Moore/south OKC [Oklahoma City]

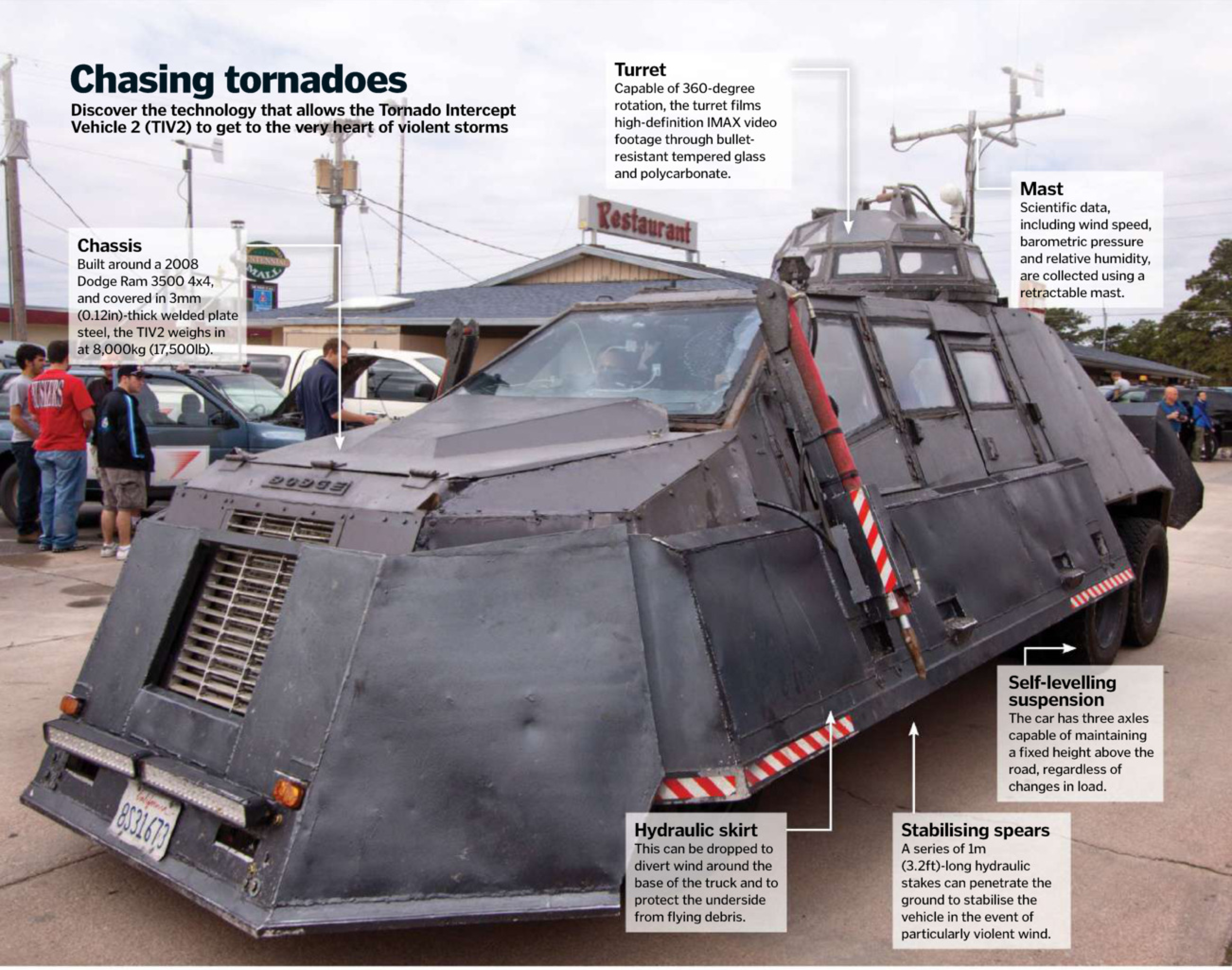


3.03pm
This is as serious as it gets for SW OKC and Moore. Please seek shelter now!

DID YOU KNOW? *Winds in a tornado have been recorded reaching speeds of 480km/h (300mph)!*

Chasing tornadoes

Discover the technology that allows the Tornado Intercept Vehicle 2 (TIV2) to get to the very heart of violent storms



Turret
Capable of 360-degree rotation, the turret films high-definition IMAX video footage through bullet-resistant tempered glass and polycarbonate.

Mast
Scientific data, including wind speed, barometric pressure and relative humidity, are collected using a retractable mast.

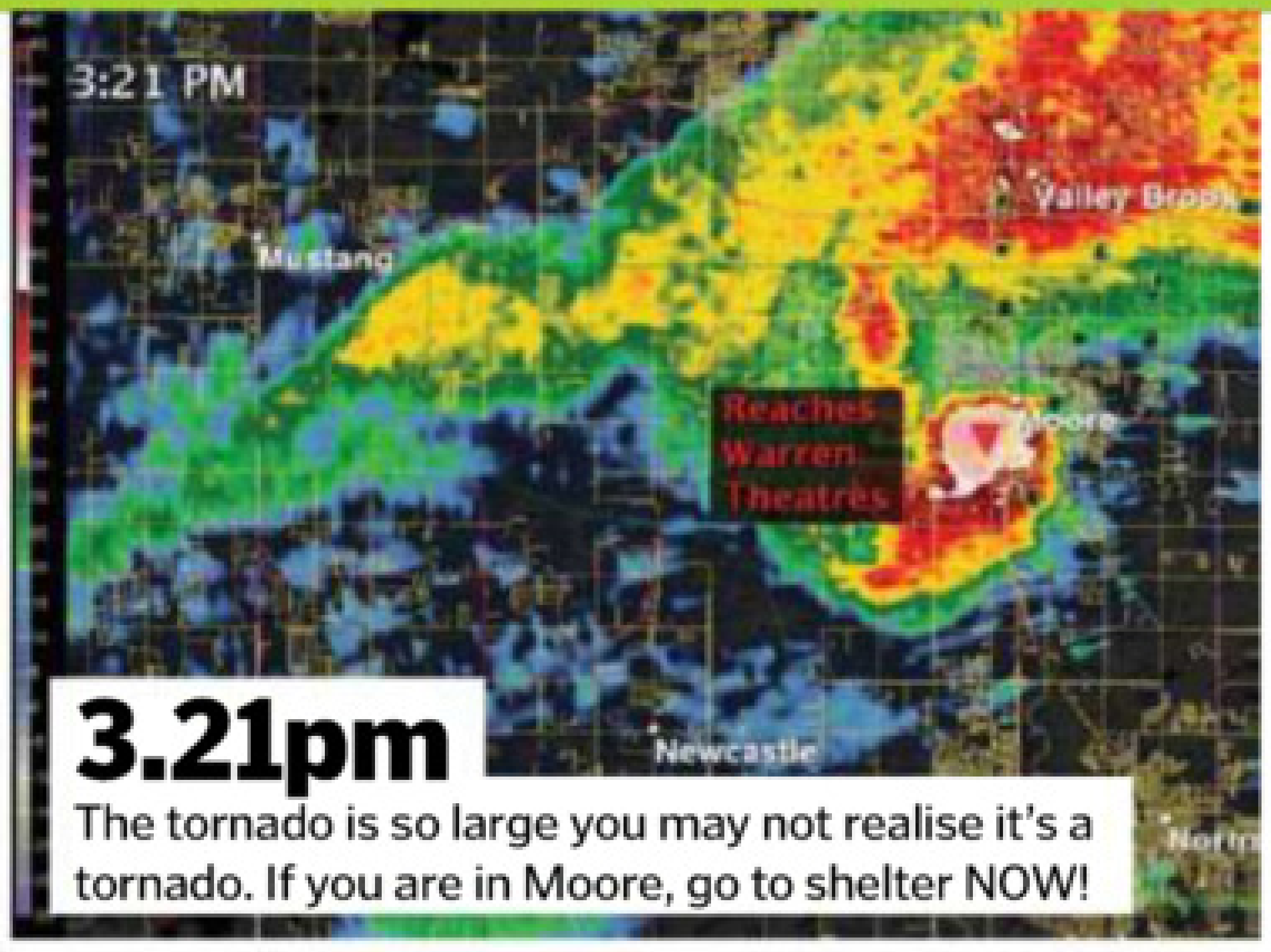
Chassis
Built around a 2008 Dodge Ram 3500 4x4, and covered in 3mm (0.12in)-thick welded plate steel, the TIV2 weighs in at 8,000kg (17,500lb).

Self-levelling suspension
The car has three axles capable of maintaining a fixed height above the road, regardless of changes in load.

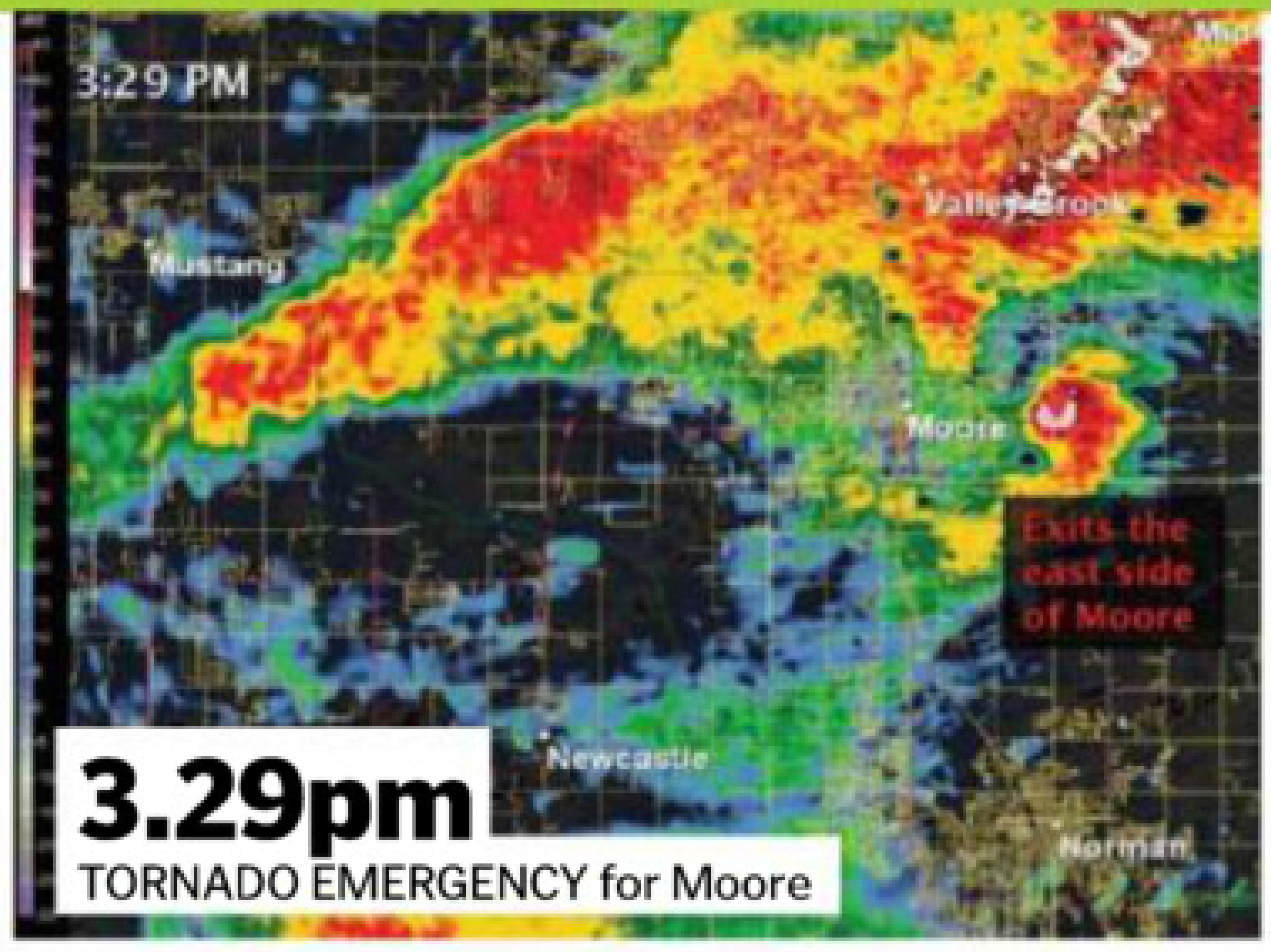
Hydraulic skirt
This can be dropped to divert wind around the base of the truck and to protect the underside from flying debris.

Stabilising spears
A series of 1m (3.2ft)-long hydraulic stakes can penetrate the ground to stabilise the vehicle in the event of particularly violent wind.

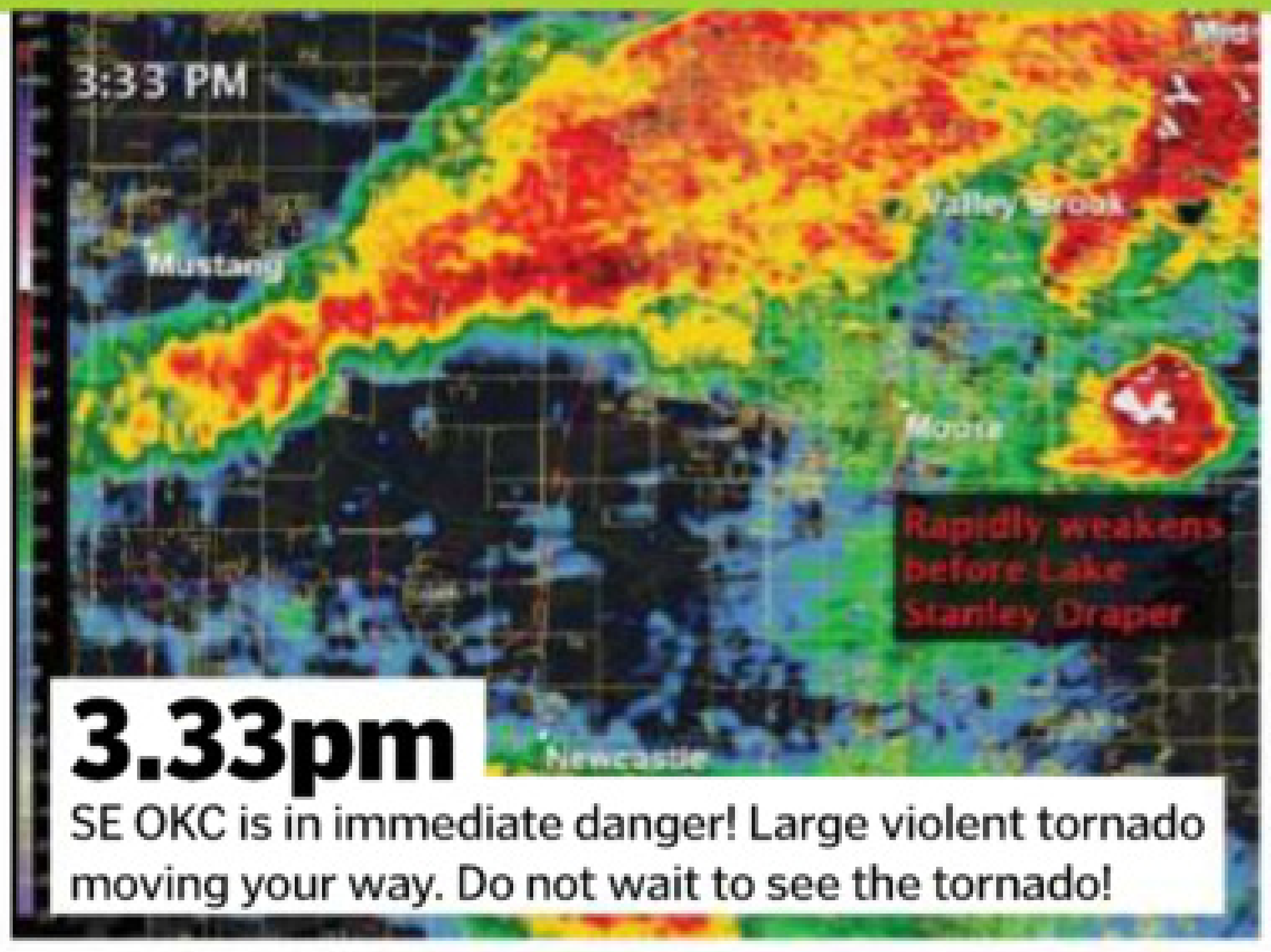
(@NWSNorman) reporting on the Oklahoma City twister as it played out



3.21pm
The tornado is so large you may not realise it's a tornado. If you are in Moore, go to shelter NOW!



3.29pm
TORNADO EMERGENCY for Moore



3.33pm
SE OKC is in immediate danger! Large violent tornado moving your way. Do not wait to see the tornado!

© Alamy; Corbis

Firestorms

From tornado-force winds to superhot flames, dare you discover nature's most violent infernos?

RECORD BREAKERS
HOT DOWN UNDER

50,000km^2

BIGGEST-EVER BUSHFIRE

The Black Thursday bushfires on 6 February 1851 burnt the largest area of any Australian bushfire in European-recorded history: a quarter of Victoria!

DID YOU KNOW? *Large wildfires have increased by 300 per cent in western USA since the mid-Eighties*

Firestorms are among nature's most violent and unpredictable phenomena. Tornado-force winds sweep superhot flames of up to 1,000 degrees Celsius (1,800 degrees Fahrenheit) through buildings and forests alike. Victims often suffocate before they can flee and entire towns can be obliterated. Survivors of firestorms describe darkness, 100-metre (330-foot)-high fireballs and a roaring like a jumbo jet. To give you an idea of the sheer heat, firestorms can be hot enough to melt aluminium and tarmac, warp copper and even turn sand into glass.

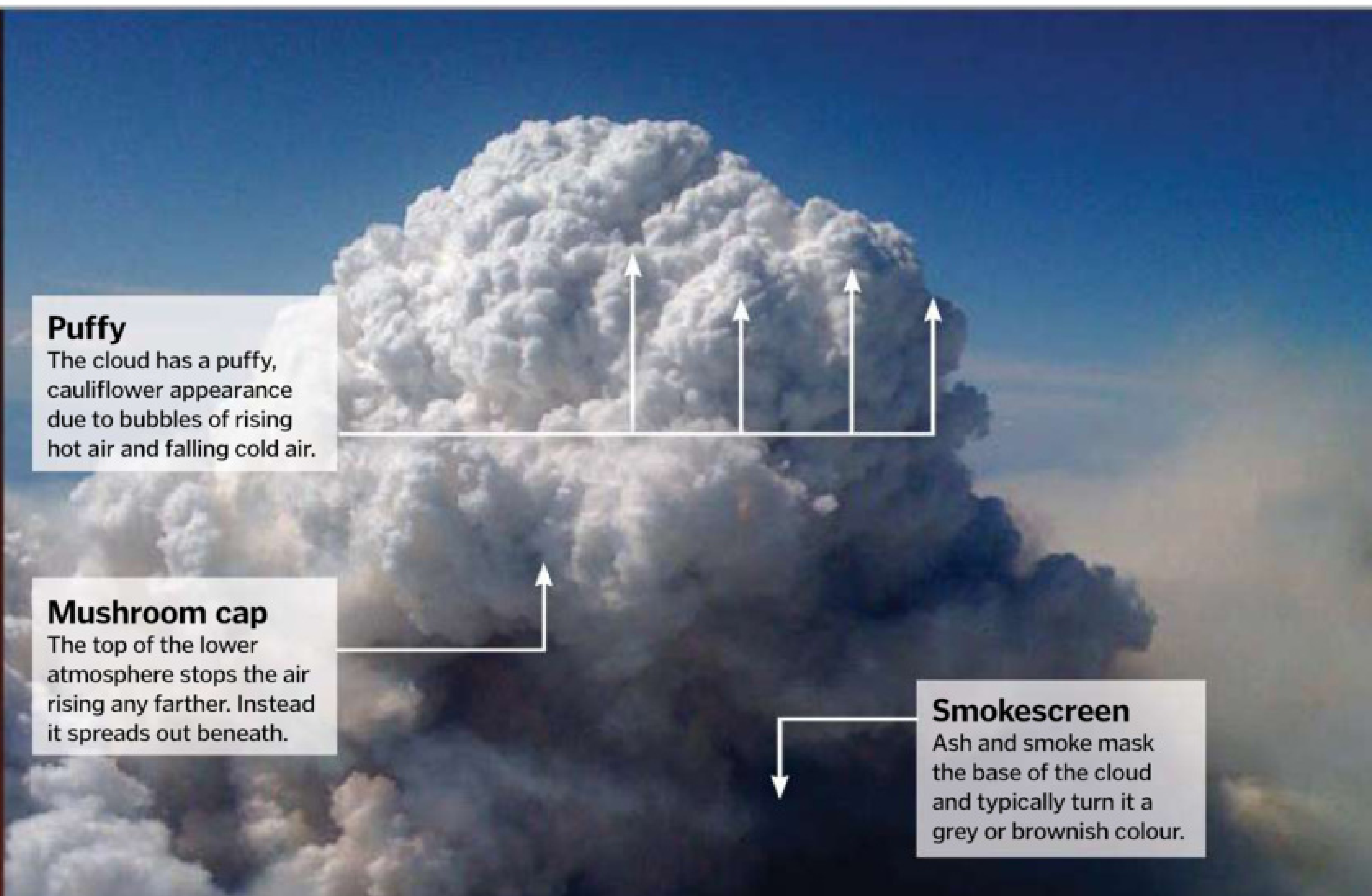
Firestorms happen worldwide, especially in the forests of the United States and Indonesia, and in the Australian bush. They occur mostly in summer and autumn when vegetation is tinder dry. Although they are a natural phenomenon, among the most devastating were triggered deliberately. During World War II, for instance, Allied forces used incendiaries and explosives to create devastating firestorms in Japanese and German cities. Firestorms also erupted after the cataclysmic impact 65.5 million years ago that many believe to have triggered the extinction of the dinosaurs.

Climate change may be already increasing the risk of mega-fires by making summers ever hotter and drier. The Rocky Mountain Climate Organization, for example, has reported that from 2003 to 2007, the 11 western US states warmed by an average of one degree Celsius (1.7 degrees Fahrenheit). The fire danger season has gone up by 78 days since 1986.

The risk of an Australian firestorm striking a major city has also heightened in the last 40 years. Climate change may have exacerbated this by increasing the risk of long heat waves and extremely hot days. In January 2013 alone, a hundred bushfires raged through the states of New South Wales, Victoria and Tasmania following a record-breaking heat wave. Maximum daily temperatures rose to 40.3 degrees Celsius (104.5 degrees Fahrenheit), beating the previous record set in 1972.

Firestorms can happen during bush or forest fires, but are not simply wildfires. Indeed, a firestorm is massive enough to create its own weather (see boxout). The thunderstorms, powerful winds and fire whirls – mini tornadoes of spinning flames – it can spawn are all part of its terrifying power.

The intense fire can have as much energy as a thunderstorm. Hot air rises above it, sucking in additional oxygen and dry debris, which fuel and spread the fire. Winds can reach



Puffy
The cloud has a puffy, cauliflower appearance due to bubbles of rising hot air and falling cold air.

Mushroom cap
The top of the lower atmosphere stops the air rising any farther. Instead it spreads out beneath.

Smokescreen
Ash and smoke mask the base of the cloud and typically turn it a grey or brownish colour.

How do mushroom clouds form?

The terrifying mushroom clouds produced after nuclear bombs are examples of pyrocumulus, or fire, clouds. This towering phenomenon is caused by intense ground heating during a firestorm. Their tops can reach an incredible nine kilometres (six miles) above the ground. When the fire heats the air, it rises in a powerful updraft that lifts water vapour, ash and dust. The vapour starts to cool high in the atmosphere and condenses as water droplets on the ash. As a result, a cloud forms that can quickly become a thunderstorm with lightning and rain, if enough water is available. The lightning can start new fires, but on the bright side, rain can extinguish them.

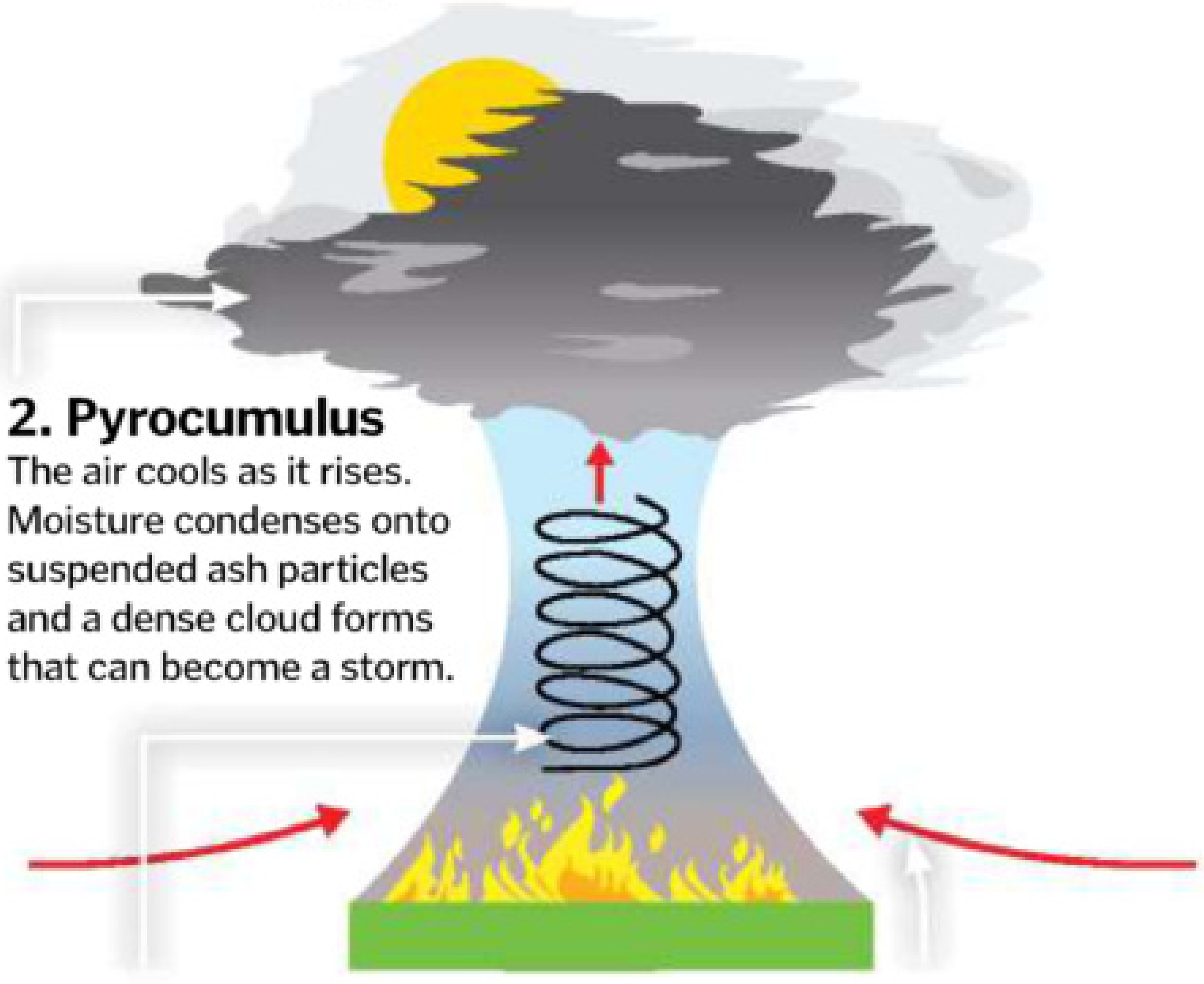
How firestorms change the weather

Firestorms can release as much energy as a lightning storm on a hot summer's afternoon.

Warm air above the fire is lighter than the surrounding air so it rises; the swirling pillar of lifting air above the fire is called a thermal column. This tornado-like structure is responsible for a firestorm's power. Under the right weather conditions, air can rise inside the column at eye-watering speeds of 270 kilometres (170 miles) per hour!

Cooler air gusts into the space left behind by the ascending air, causing violent winds that merge fires together into a single intense entity. They also blow in oxygen, wood and other flammable material that serve to fuel and intensify the blaze.

Turbulent air spiralling around the thermal column can spawn fire tornadoes and throw out sparks. These can set light to trees and houses tens of metres away, increasing the conflagration's range.



2. Pyrocumulus
The air cools as it rises. Moisture condenses onto suspended ash particles and a dense cloud forms that can become a storm.

1. Thermal column
The fire warms the air above, causing it to become lighter than its surroundings so it rises.

3. Filling the gap
Air rushes into the space left by the rising air, creating violent gusts that only intensify the fire.

tornado speed – tens of times the ambient wind speeds. The huge pillar of rising air – called a thermal column – swirling above the firestorm can generate thunderclouds and even lightning strikes that spark new fires.

The thermal column, in turn, can spawn a number of fiery tornadoes, which can tower to 200 metres (650 feet) and stretch 300 metres (980 feet) wide, lasting for at least 20 minutes. These fling flaming logs and other burning debris across the landscape, spreading the blaze. The turbulent air can gust at 160 kilometres (100 miles) per hour, scorching hillsides as far as 100 metres (330 feet) away from the main fire. It's far more powerful than a typical wildfire, which moves at around 23 kilometres (14.3 miles) per hour – just under the average human sprint speed.

Like all fires, firestorms need three things to burn. First is a heat source for ignition and to dry fuel so it burns easier. Fuel, the second must, is anything that combusts, whether that be paper, grass or trees. Thirdly, all fires need at least 16 per cent oxygen to facilitate their chemical processes. When wood or other fuel burns, it reacts with oxygen in the surrounding air to release heat and generate smoke, embers and various gases. Firestorms are so intense that they often consume all available oxygen, suffocating those who try to take refuge in ditches, air-raid shelters or cellars. ✽

Fighting firestorms

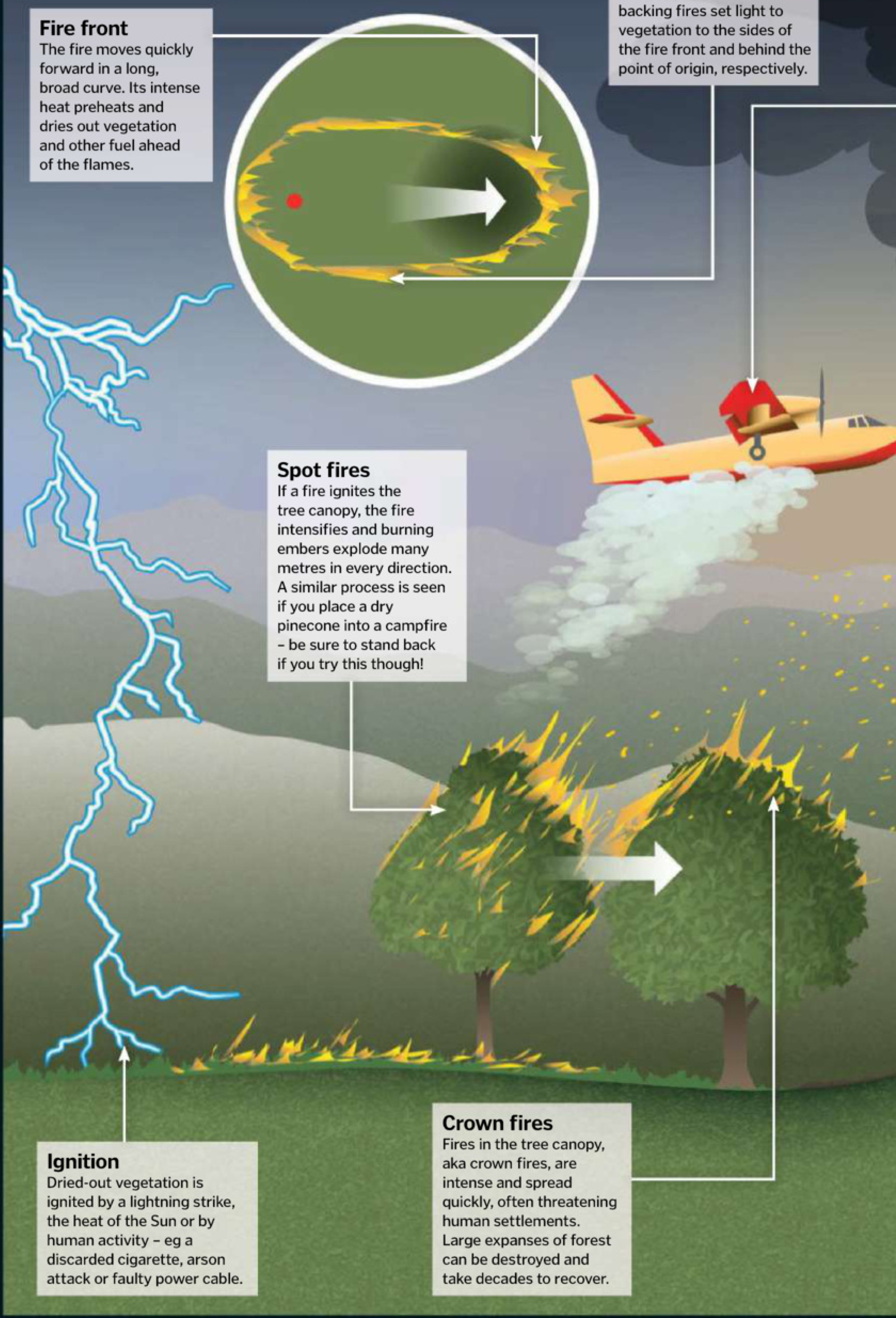
Fire wardens, air patrols and lookout stations all help detect fires early, before they can spread. Once a fire starts, helicopters and air tankers head to the scene. They spray thousands of gallons of water, foam or flame-retardant chemicals around the conflagration. In the meantime, firefighters descend by rope or parachute to clear nearby flammable material.

We can reduce the risk of fire breaking out in the first place by burning excess vegetation under controlled conditions. Surprisingly this can actually benefit certain plants and animals. Canadian lodgepole pines, for example, rely partly on fire to disperse their seeds. Burning also destroys diseased trees and opens up congested woodland to new grasses and shrubs, which provides food for cattle and deer.

Vegetation in fire-prone areas often recovers quickly from a blaze. Plants like Douglas fir, for instance, have fire-resistant bark – although it can only withstand so much heat. Forest owners help flora to return by spreading mulch, planting grass seed and erecting fences.

Firestorm step-by-step

See how a deadly firestorm starts as a single spark and spreads rapidly through the forest



Fire front
The fire moves quickly forward in a long, broad curve. Its intense heat preheats and dries out vegetation and other fuel ahead of the flames.

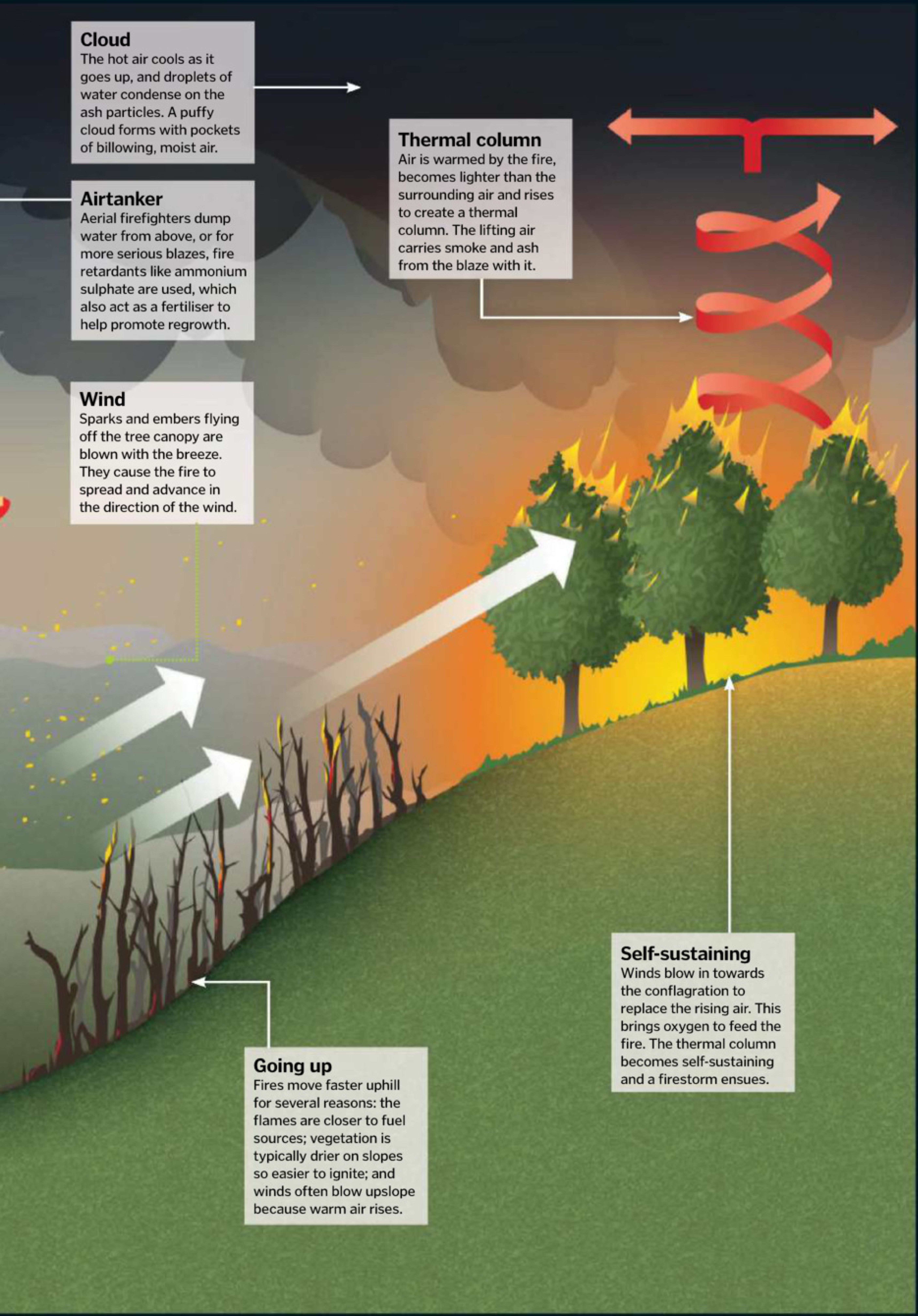
Flanking and backing fires
The fire front burns any fuel ahead. Flanking and backing fires set light to vegetation to the sides of the fire front and behind the point of origin, respectively.

Spot fires
If a fire ignites the tree canopy, the fire intensifies and burning embers explode many metres in every direction. A similar process is seen if you place a dry pinecone into a campfire – be sure to stand back if you try this though!

Ignition
Dried-out vegetation is ignited by a lightning strike, the heat of the Sun or by human activity – eg a discarded cigarette, arson attack or faulty power cable.

Crown fires
Fires in the tree canopy, aka crown fires, are intense and spread quickly, often threatening human settlements. Large expanses of forest can be destroyed and take decades to recover.

DID YOU KNOW? *The biggest man-made firestorm took place in Dresden, Germany, in 1945; 70 per cent of the city was destroyed*



Cloud
The hot air cools as it goes up, and droplets of water condense on the ash particles. A puffy cloud forms with pockets of billowing, moist air.

Airtanker
Aerial firefighters dump water from above, or for more serious blazes, fire retardants like ammonium sulphate are used, which also act as a fertiliser to help promote regrowth.

Wind
Sparks and embers flying off the tree canopy are blown with the breeze. They cause the fire to spread and advance in the direction of the wind.

Thermal column
Air is warmed by the fire, becomes lighter than the surrounding air and rises to create a thermal column. The lifting air carries smoke and ash from the blaze with it.

Self-sustaining
Winds blow in towards the conflagration to replace the rising air. This brings oxygen to feed the fire. The thermal column becomes self-sustaining and a firestorm ensues.

Going up
Fires move faster uphill for several reasons: the flames are closer to fuel sources; vegetation is typically drier on slopes so easier to ignite; and winds often blow upslope because warm air rises.

Five mega firestorms

1 Black Saturday

In 2009, one of Australia's worst bushfires killed 173 people, injured 5,000, destroyed 2,029 homes, killed numerous animals and burnt 4,500 square kilometres (1,700 square miles) of land. Temperatures may have reached 1,200 degrees Celsius (2,192 degrees Fahrenheit).

2 Great Peshtigo

The deadliest fire in American history claimed 1,200-2,500 lives, burned 4,860 square kilometres (1,875 square miles) of Wisconsin and upper Michigan and destroyed all but two buildings in Peshtigo in 1871.

3 Ash Wednesday

More than 100 fires swept across Victoria and South Australia on 16 February 1983, killing 75 people, destroying 3,000 homes and killing 50,000 sheep and cows. It was the worst firestorm in South Australia's history.

4 Hamburg

This firestorm brought on by an Allied bomb strike in 1943 killed an estimated 44,600 civilians, left many more homeless and levelled a 22-square-kilometre (8.5-square-mile) area of the German city. Hurricane-force winds of 240 kilometres (150 miles) per hour were raised.

5 Great Kanto

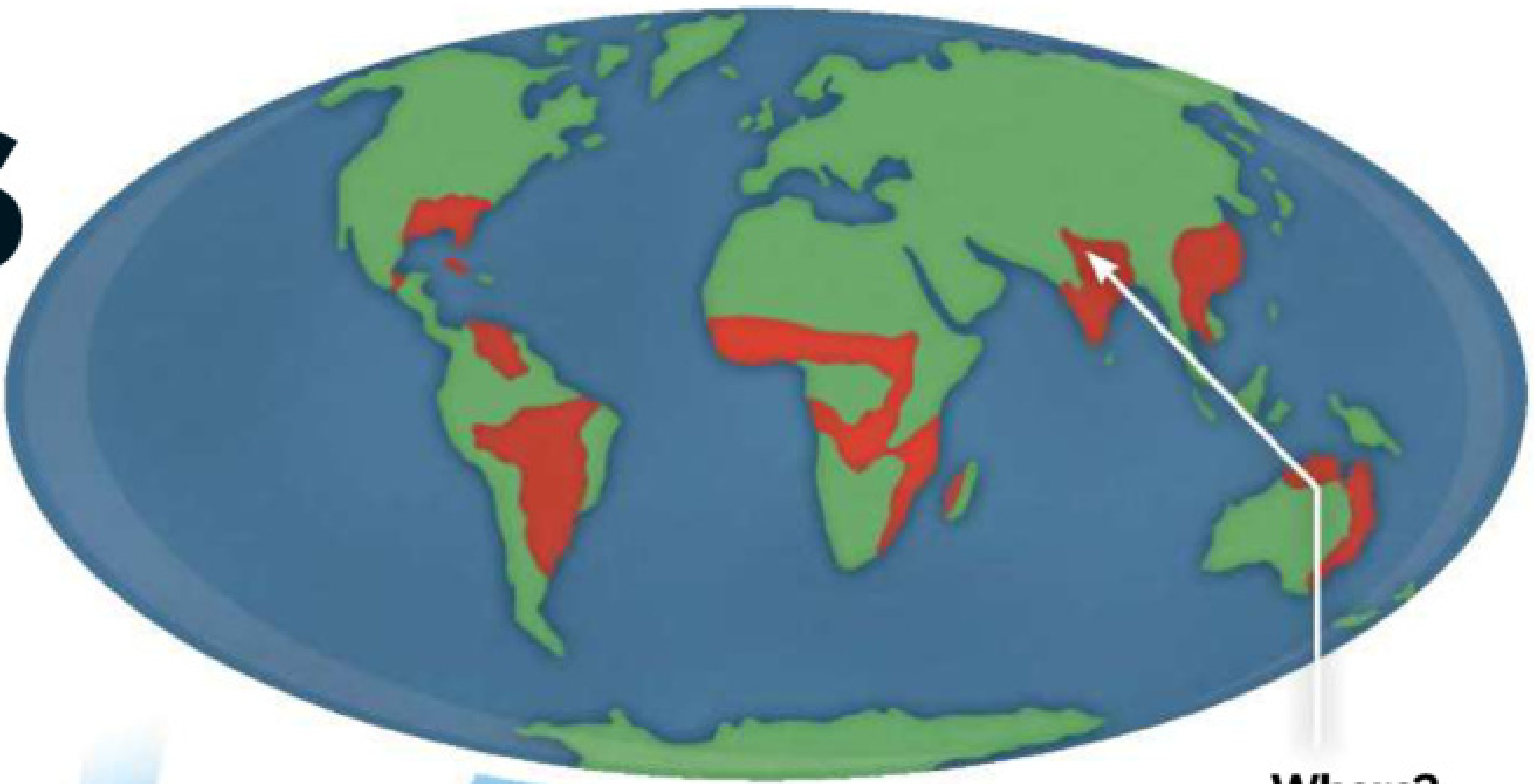
A 7.9-magnitude earthquake on 1 September 1923 triggered a firestorm that burned 45 per cent of Tokyo and killed over 140,000. This included 44,000 who were incinerated by a 100-metre (330-foot) fire tornado.

© Alamy; Thinkstock; Peters & Zabransky

Monsoons

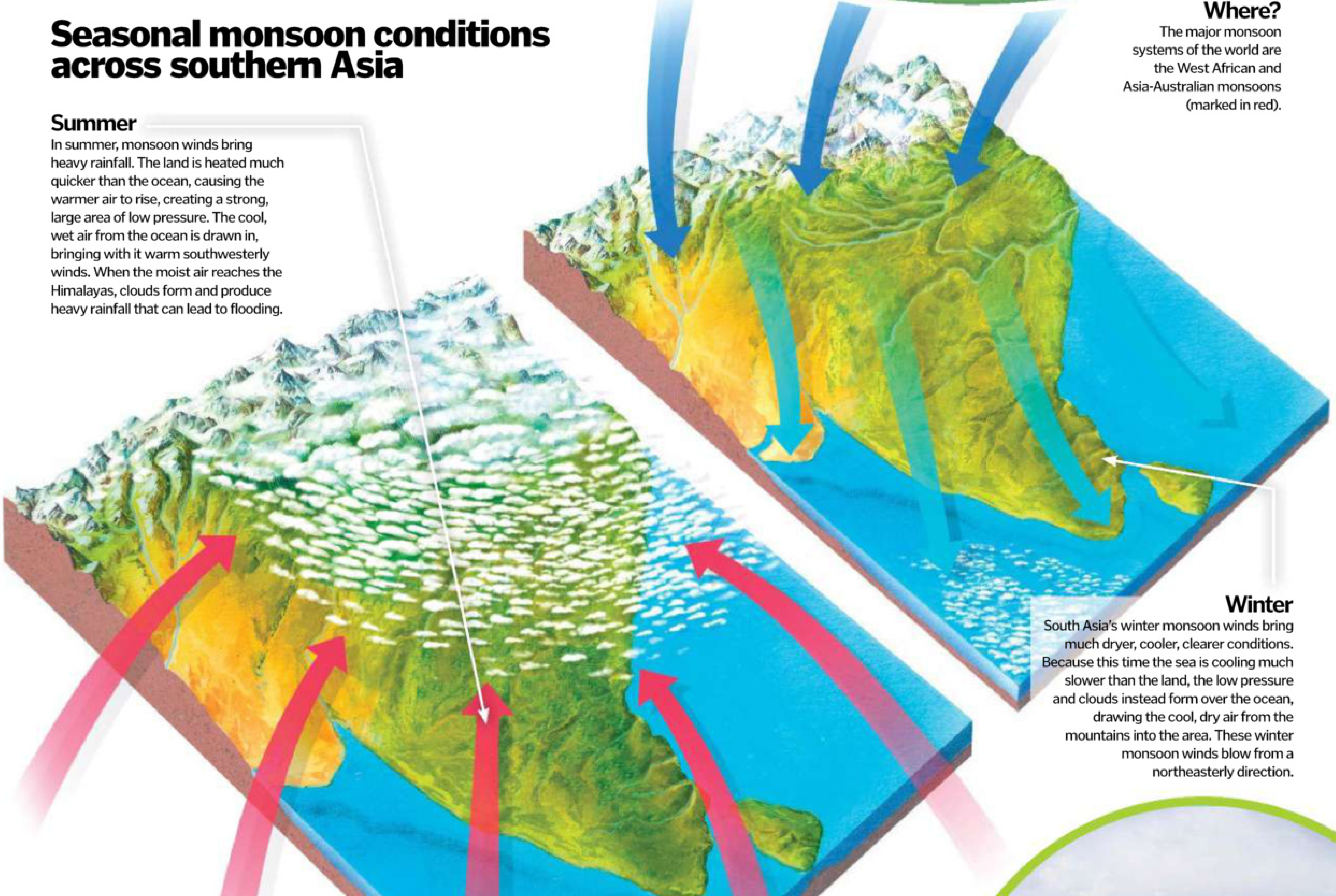
The wind systems that reverse seasonally, bringing dramatically different weather to subtropical regions

Monsoons are seasonal wind systems occurring in tropical and subtropical regions south, southeast and east of the large landmasses in the northern hemisphere. They see the prevailing wind direction and conditions in these areas reverse between summer and winter.



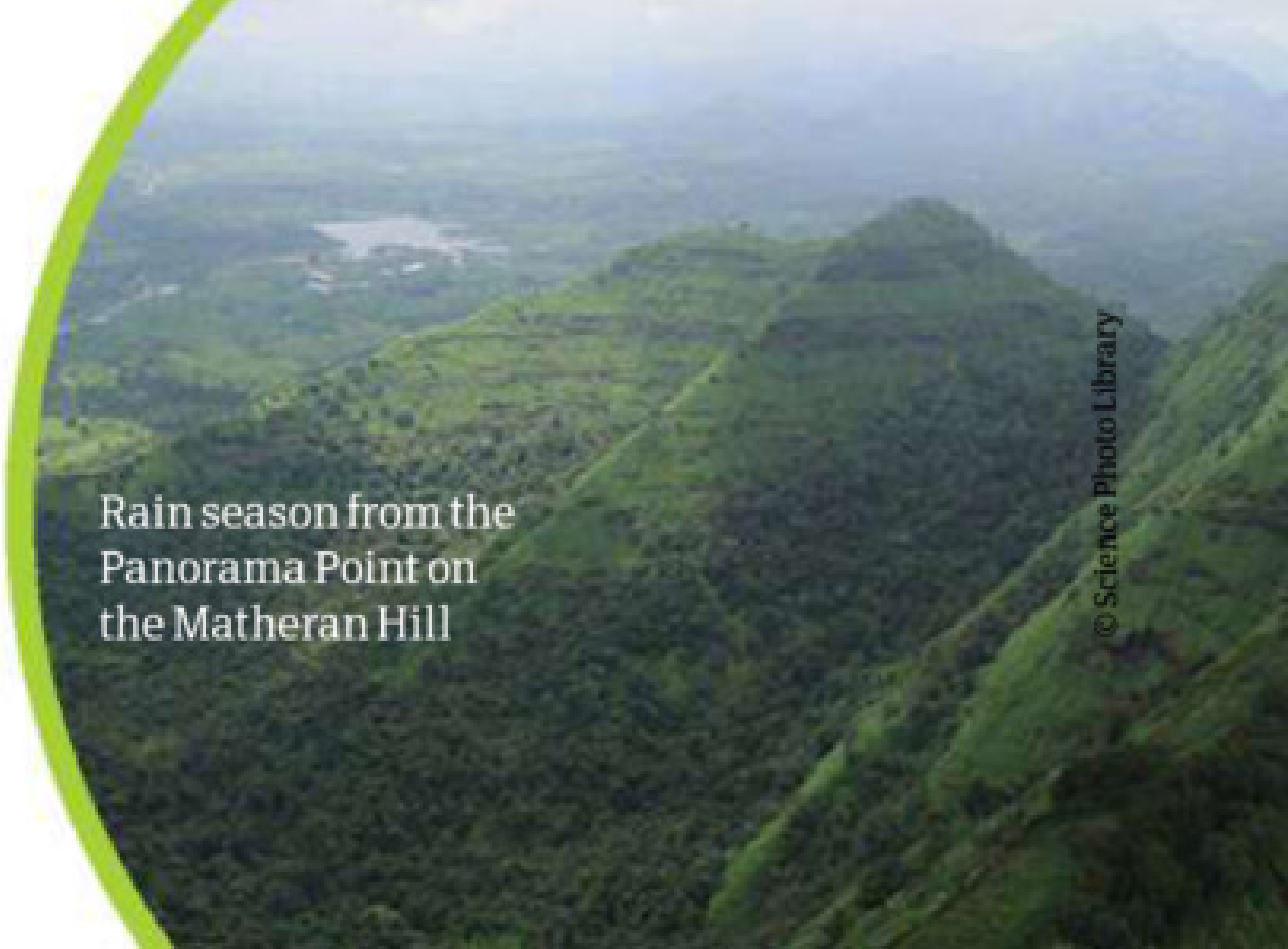
Where?
The major monsoon systems of the world are the West African and Asia-Australian monsoons (marked in red).

Seasonal monsoon conditions across southern Asia



Summer
In summer, monsoon winds bring heavy rainfall. The land is heated much quicker than the ocean, causing the warmer air to rise, creating a strong, large area of low pressure. The cool, wet air from the ocean is drawn in, bringing with it warm southwesterly winds. When the moist air reaches the Himalayas, clouds form and produce heavy rainfall that can lead to flooding.

Winter
South Asia's winter monsoon winds bring much dryer, cooler, clearer conditions. Because this time the sea is cooling much slower than the land, the low pressure and clouds instead form over the ocean, drawing the cool, dry air from the mountains into the area. These winter monsoon winds blow from a northeasterly direction.



Rain season from the Panorama Point on the Matheran Hill

© Science Photo Library

5 TOP FACTS AVALANCHES

The thick of it

1 A large avalanche might release up to 300,000 cubic yards of snow, which is equivalent to something like 20 football pitches covered with ten feet of snow.

The white killer

2 Each year, avalanches kill around 150 people – the victims are usually males in their twenties who are experienced mountaineers or skiers more likely to take risks.

Fresh snow = bad news

3 A snow-faring adventurer is most likely to witness an impressive avalanche during or just after a storm that has deposited around 30cm of fresh snow.

Breath of life

4 If caught under an avalanche, wait for the slide to stop and then use your hands to clear an area in which to breathe, then punch a fist upwards and outwards.

Intentional avalanches

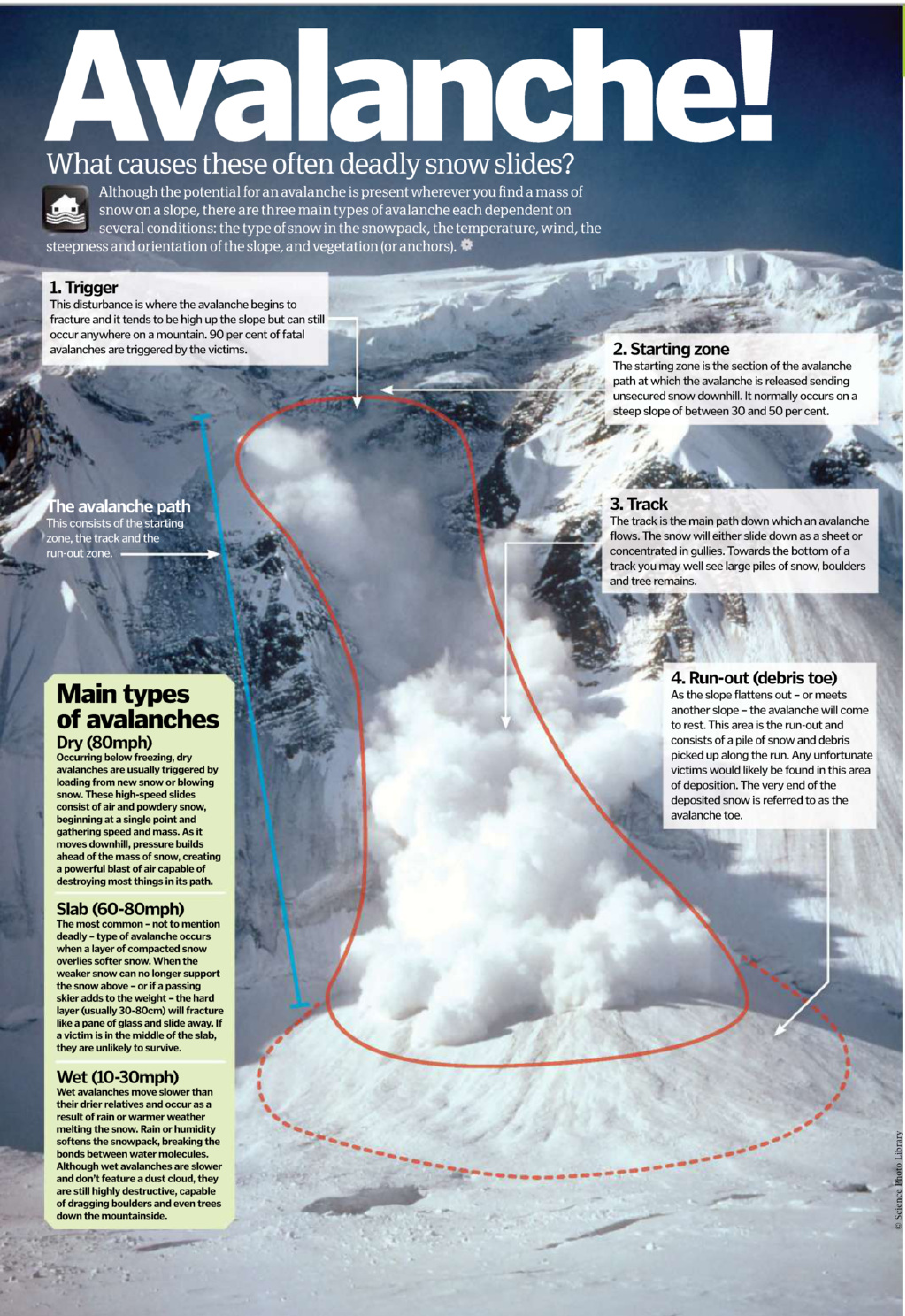
5 When a lot of snow builds on a slope where an avalanche is likely, small avalanches are intentionally triggered using explosives to prevent one potentially deadly slide.

DID YOU KNOW? *A noise cannot trigger an avalanche; it's a myth – a plot device fabricated for films*

Avalanche!

What causes these often deadly snow slides?

Although the potential for an avalanche is present wherever you find a mass of snow on a slope, there are three main types of avalanche each dependent on several conditions: the type of snow in the snowpack, the temperature, wind, the steepness and orientation of the slope, and vegetation (or anchors).



1. Trigger

This disturbance is where the avalanche begins to fracture and it tends to be high up the slope but can still occur anywhere on a mountain. 90 per cent of fatal avalanches are triggered by the victims.

2. Starting zone

The starting zone is the section of the avalanche path at which the avalanche is released sending unsecured snow downhill. It normally occurs on a steep slope of between 30 and 50 per cent.

The avalanche path

This consists of the starting zone, the track and the run-out zone.

3. Track

The track is the main path down which an avalanche flows. The snow will either slide down as a sheet or concentrated in gullies. Towards the bottom of a track you may well see large piles of snow, boulders and tree remains.

4. Run-out (debris toe)

As the slope flattens out – or meets another slope – the avalanche will come to rest. This area is the run-out and consists of a pile of snow and debris picked up along the run. Any unfortunate victims would likely be found in this area of deposition. The very end of the deposited snow is referred to as the avalanche toe.

© Science Photo Library

Main types of avalanches

Dry (80mph)

Occurring below freezing, dry avalanches are usually triggered by loading from new snow or blowing snow. These high-speed slides consist of air and powdery snow, beginning at a single point and gathering speed and mass. As it moves downhill, pressure builds ahead of the mass of snow, creating a powerful blast of air capable of destroying most things in its path.

Slab (60-80mph)

The most common – not to mention deadly – type of avalanche occurs when a layer of compacted snow overlies softer snow. When the weaker snow can no longer support the snow above – or if a passing skier adds to the weight – the hard layer (usually 30-80cm) will fracture like a pane of glass and slide away. If a victim is in the middle of the slab, they are unlikely to survive.

Wet (10-30mph)

Wet avalanches move slower than their drier relatives and occur as a result of rain or warmer weather melting the snow. Rain or humidity softens the snowpack, breaking the bonds between water molecules. Although wet avalanches are slower and don't feature a dust cloud, they are still highly destructive, capable of dragging boulders and even trees down the mountainside.

Interview

We spoke to **Cam Campbell**, public avalanche forecaster for the Canadian Avalanche Centre, to find out more

How It Works: What are the most common avalanche triggers?

Cam Campbell: The most common triggers for all types of avalanches are natural; [including] loading from new snow, rain or blowing snow, rapid warming of the snowpack from an increase in air temperature or intense solar radiation, falling cornices, or other natural snowpack stressors. […] Most fatal avalanches are human-triggered by the victim or someone in their party.

HIW: How and why are avalanches sometimes triggered intentionally?

CC: [Avalanches are triggered intentionally] to reduce the threat of future uncontrolled avalanches. Any time an avalanche is intentionally triggered, strict procedures, such as access closures and spotters are in place to ensure nobody will be adversely affected. Ski resorts or commercial backcountry operations often stabilise slopes by triggering avalanches before opening to the public. Intentional triggering can be achieved safely through remote-controlled explosives well away from the avalanche path, or hand- or helicopter-deployed explosives above the path.

Survival tips

The top ten survival tips for mountaineers and skiers

- ☑ Take avalanche safety course
- ☑ Read avalanche bulletin
- ☑ Choose route or terrain appropriate for conditions
- ☑ Carry and practise using safety gear (transceiver, shovel and probe)
- ☑ Never travel alone
- ☑ Avoid common trigger points such as convexities, thin areas, or below protruding rocks or trees
- ☑ Travel on avalanche prone slopes one person at a time and spot from safe locations
- ☑ If caught do everything in your power to escape the flowing mass
- ☑ If burial is imminent, create an air pocket in front of your face with hands and arms
- ☑ If buried, remain calm and await rescue

Killer storms

The making of a tsunami

How a deep-sea rumble forges a killer wave

On 26 December 2004, a 9.0 magnitude earthquake off the coast of Sumatra, Indonesia triggered a series of tsunamis – giant seismic sea waves. It was deadliest natural disaster in recorded history.

Tsunamis are not 'tidal' waves. They are created when a violent geological event – like a submarine earthquake, landslide or underwater volcanic eruption – displaces a huge amount of water.

The Indian Ocean earthquake occurred along a subduction zone, a place where one tectonic plate wedges under another. During the record-setting quake – which released more energy than 23,000 Hiroshima-era atomic bombs – a section of sea floor 1,000 kilometres long was pushed ten metres horizontally and several meters vertically.

The violent displacement generated a massive deep-ocean wave only a few meters high, but hundreds of kilometres long. The almost imperceptible swell travelled across the open water as fast as a jet aeroplane. As the deep-ocean seismic wave neared the shore, it was slowed down by the quickly rising sea floor. But as the wave compressed horizontally, it rose vertically, reaching heights of 30 metres in some cases.

DID YOU KNOW?

The most tornadoes...

There are more tornadoes in America than any other country. Supercell formation is fuelled by warm, moist air from the Gulf of Mexico meeting cool, dry air blowing over the Rockies.

DID YOU KNOW? on April 3, 1974, when a two-day "Super Outbreak" of 147 tornadoes killed 308 people in 13 states

Marvel at the raw power of nature at its nastiest

A gust of air rattles the windows. The sky darkens ominously as coal-black clouds creep across the horizon. Thunder rumbles thickly in the distance accompanied by the first flickers of lightning, like paparazzi.

Suddenly, the rain comes down in sheets, blown sideways by howling winds. With a crackling explosion, a tree across the street is torn in half by a stroke of lightning. But as suddenly as it started, the rain stops. The clouds remain low and terribly dark, almost green. You look out the back window in search of a reprieve. Instead, you see the twister.

Mother Nature deserves respect. Before you complain about the light drizzle that spoiled your picnic, thank your lucky stars you've never experienced a true weather disaster: a six-story tsunami wave, 150kph hurricane winds, or tornadoes that can toss an 18-wheeler like a Matchbox car.

We'll help you make sense of the Weather Channel chatter and learn what causes the world's most extreme weather phenomena.

Tornadoes explained

Why twisters descend from the sky and drill a path of destruction

Tornadoes are born in beefed-up storm clouds called supercells. While normal storm clouds form and dissipate in 30 minutes, supercells can last for hours and spread severe weather across hundreds of kilometres. But the most unique characteristic of a supercell is its powerful counter-clockwise rotation.

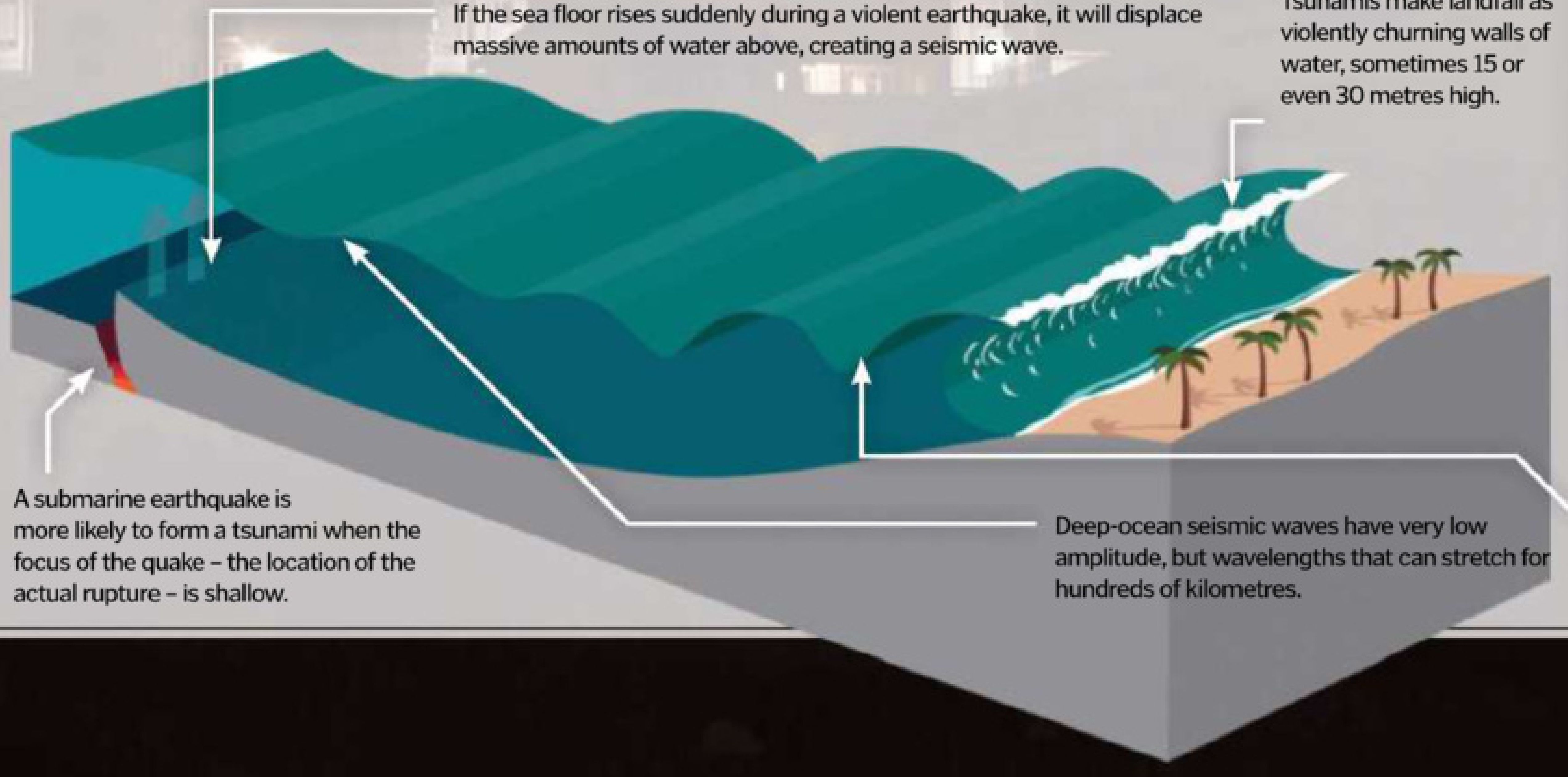
Supercells start like normal thunderstorms. Moist, warm air near the surface is pushed aloft by a physical force like a cold front. The warm air condenses into water droplets as it reaches higher altitudes, forming towering clouds. Supercells grow large because of an abundance of warm, wet air below and cool, dry air above.

But why do they rotate? It's down to a phenomenon called wind shear, a sudden change of wind speed and direction. Typically, winds blow faster the higher you climb. This creates a paddle wheel effect in the atmosphere, generating columns of air that spin on horizontal axes.

With supercells, the warm, low-lying air is sucked up into the storm with such force that it grabs one of these horizontally rotating columns of air and twists it vertically. The result is a mesocyclone, an intensely rotating column at the heart of the supercell. Meanwhile, rain and hail falling from the supercell are caught in these rotating winds. Much of the precipitation evaporates, releasing pockets of cool air that pull downward on the swirling vortex.

As intensely rotating winds reach the ground, friction slows the effects of centrifugal force, tightening the funnel. There is incredibly low air pressure inside the funnel, which acts like a vacuum. As more and more air is sucked into the vortex, the speed of rotation increases, like a figure skater pulling in her arms for the final head-spinning twirl.

The resulting tornado can generate winds over 300mph, tear through reinforced structures like a buzz saw, lift large vehicles, and flatten homes.


If the sea floor rises suddenly during a violent earthquake, it will displace massive amounts of water above, creating a seismic wave.
Tsunamis make landfall as violently churning walls of water, sometimes 15 or even 30 metres high.
A submarine earthquake is more likely to form a tsunami when the focus of the quake – the location of the actual rupture – is shallow.
Deep-ocean seismic waves have very low amplitude, but wavelengths that can stretch for hundreds of kilometres.
As the tsunami approaches the shore, the rising sea floor compresses the wavelength, greatly increasing the amplitude.

Deadly force

Later waves are usually the deadliest, launching masses of debris on-shore

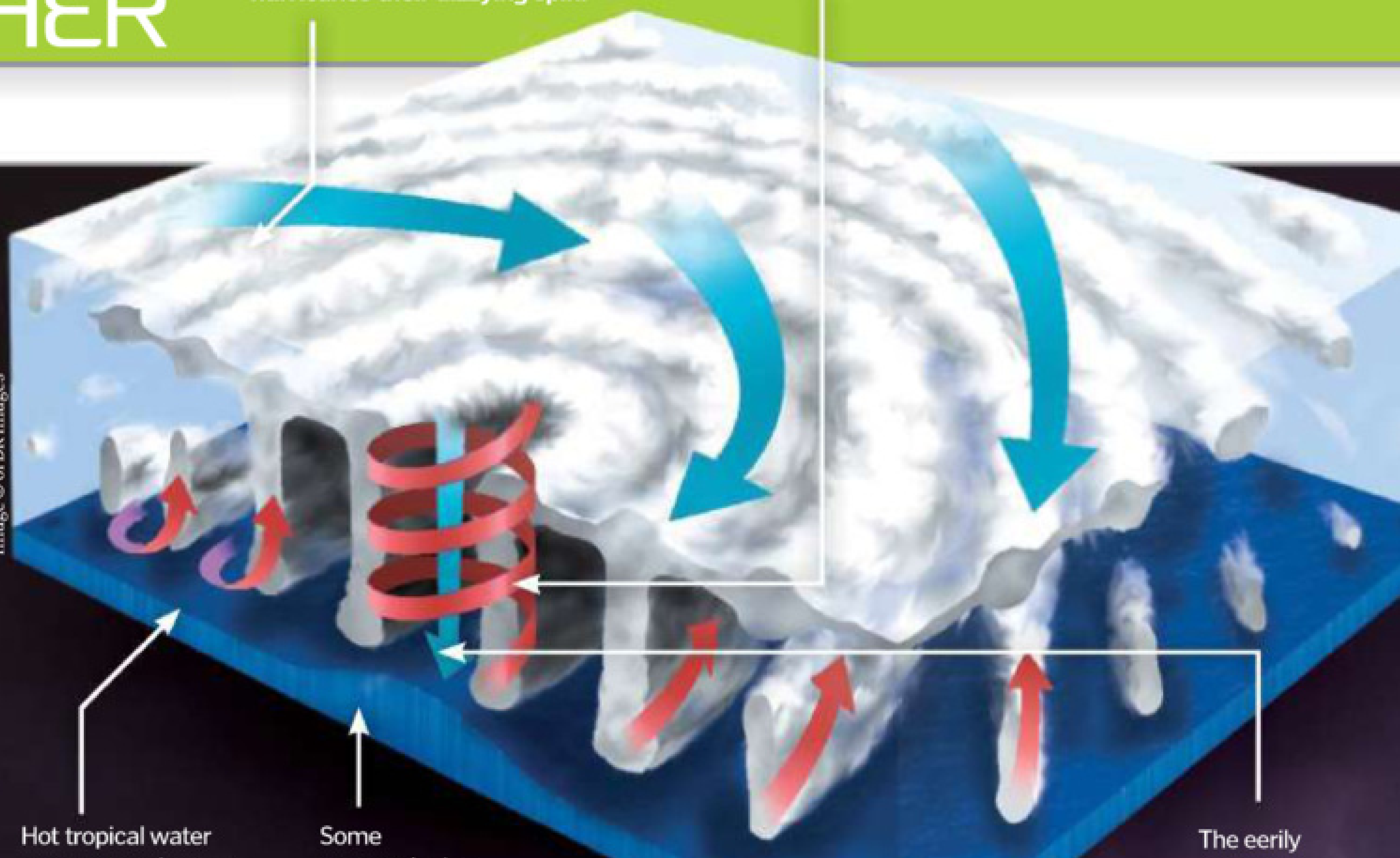
There's a storm coming…

The origins of hurricanes, a deadly force of nature

Hurricanes are massive heat engines. They form over tropical waters with a minimum temperature of 27°C (80°F). Hot water evaporates very quickly, rising up through the atmosphere until it condenses into clouds and water droplets. The incredible thing is that condensation itself creates even more heat. The recharged air soars even higher, building a cluster of towering, fat thunderstorms called a tropical disturbance.

Once the heat engine has been jump-started, rapid condensation within the storm continues to force air upward while more hot air rushes in from below to fill the void. This suction of hot air from the ocean surface creates lower and lower air pressure. When air rushes from high pressure to low pressure, it creates powerful winds. When wind velocity reaches 38mph, the storm is called a tropical depression.

Satellite images of hurricanes show a swirling vortex of storm clouds. The spin is caused by two main forces: the Coriolis force and the pressure gradient. In the northern hemisphere, the Earth's rotation pulls winds to the right (Coriolis force), but the extreme low pressure at the storm's centre pulls them back to the left, creating a net counter-clockwise spin. The opposite is true south of the equator. As the heat engine chugs on, more water condenses, more heat rises, the pressure drops further and spin increases until winds reach 39 to 74mph, enough to qualify as a tropical storm. Seven out of ten tropical storms spin even faster than 74mph, officially becoming a hurricane. ✱



A combination of the Coriolis force and pressure gradient (the rush of air from high to low pressure), give hurricanes their dizzying spin.

The eye wall – a solid ring of clouds where rain bands converge and compress – contains the hurricane's most powerful winds.

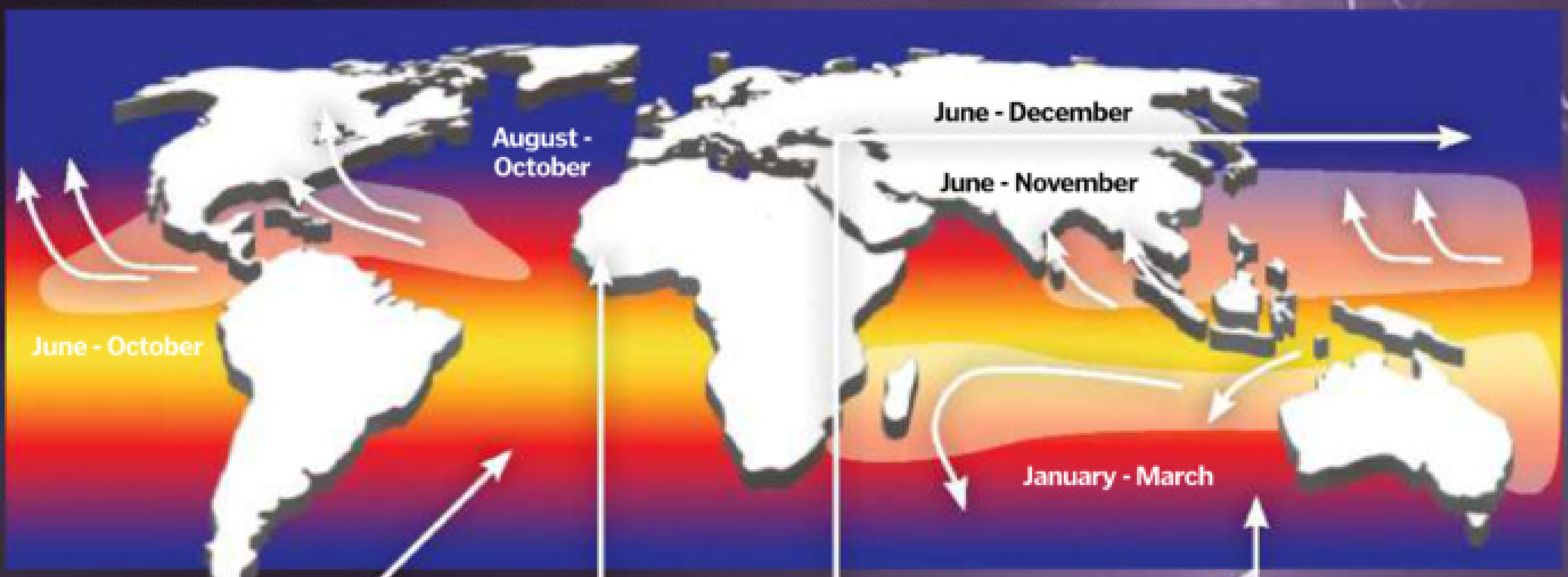
Hot tropical water evaporates, rises as vapour and condenses into rings of towering storm clouds called rain bands.

Some meteorologists believe storm surges are caused by mounds of water drawn upward by the low surface pressure in the eye of the hurricane.

The eerily calm and cloudless eye of the hurricane is the point of lowest pressure, causing air to sink straight down toward the ocean surface.

Image © of DK images

The hurricane seasons…



There are few hurricanes in the south Atlantic because high wind shear near the ocean surface shreds tropical storms.

Atlantic hurricanes begin as tropical depressions off the African coast from June to November, when the tropical waters are steamiest.

Hurricanes are called typhoons in the northwest Pacific, and they can occur year-round due to high average water temperature.

October through March is spring and summer in the southern hemisphere, meaning more cyclones (India) and willy-willys (Australia).

Extreme heat
Hundreds of lightning bolts strike the earth every second, each generating temperatures exceeding 27,000° C

Thunder and lightning

Beauty has never been so powerful…

Inside the chaos of a storm cloud, falling bits of ice collide with updrafting water droplets, shearing off electrons to create newly charged particles. The negative particles sink to the bottom of the cloud, while positive particles rise to the top, just like a colossal battery. As a storm cloud swells in size, the force of its negatively charged underside repels negative ions away from the surface of the Earth, creating a net positive charge on the ground. Something needs to correct the imbalance between theses huge oppositely charged masses.

Lightning is a violent electrical discharge between clouds and surface objects, clouds and other clouds or points within the same storm cloud. In fact, only ten per cent of lightning strikes hit the earth. Cloud-to-ground lightning begins when a negative charge from the cloud begins to carve a path of least resistance through ionised air, zigging and zagging every 25 meters. When it nears the ground, a positive charge called a 'streamer' reaches up from surface objects, completing the circuit. The resulting strike is instantaneous, travelling at 300 million m/s with the power of 100 billion volts.

A clap of thunder is caused by shock waves created by the expanding and contracting air around the superheated lightning.

5 TOP FACTS HURRICANES

The world's most powerful generator

1 If you calculate the total heat generated by condensation inside a hurricane, it equals 200 times our daily worldwide energy-generating capacity.

No-holds-barred Nancy

2 Typhoon Nancy, which tore across Japan in September 1961, clocked sustained winds of 185kph (213mph), the fastest on record.

A four-ce to be reckoned with

3 Only twice in modern history – 1893 and 1998 – did four hurricanes power their way simultaneously through the Atlantic basin.

Another myth down the drain

4 It is untrue that the Coriolis force causes toilets to flush in different directions in the northern and southern hemispheres.

A name to be remembered

5 Since the Fifties, all tropical storms and hurricanes in the Atlantic basin receive a name. If the storm's particularly deadly, the name is retired.

How are blizzards created?

These deadly winter storms can strike without warning

In January 1996, 100 million tons of snow fell on the streets of New York City and nearby Philadelphia was buried under a record 78 centimetres (30.7 inches). Ice storms and sub-zero temperatures stretched as far south as sunny Florida, trapping people in their homes, often without electricity. In 1891, easterly winds dumped 3.6 metres (11 feet) of snow in London. Trains were completely buried under tremendous drifts and 65 ships sank under the heavy ice and snow.

Blizzards form exactly like thunderstorms. A cold front pushes warmer, moist air into the atmosphere, condensing into clouds. If temperatures stay below freezing, snow falls instead of rain. If huge amounts of snow are accompanied by gale-force winds, it's possible to achieve a complete whiteout, when earth and sky merge in a disorienting canvas of white.

DID YOU KNOW? For a winter storm to qualify as a blizzard, there must be sustained winds of at least 58kph (35mph) and less than 0.4 km (0.25 mile) visibility for three hours or more.

Blanket covering!
You're going to need more than an ice scrapper to get out of this one mate…

Waterspout

While it's never truly rained 'cats and dogs', it has rained frogs and fish. In the past century, towns in the United States, Greece and Serbia have been inundated with falling amphibians (some of them frozen solid) that pile up in the streets. While a Biblical plague isn't out of the question, the more likely culprit is a waterspout, a tornado-like vortex that forms over water.

There are two kinds of waterspouts: tornadic and fair weather. Tornadic waterspouts form under the exact same conditions as tornadoes and can generate winds over 300kph (200mph) with powerful internal updrafts. The low-pressure core of the waterspout can dip several metres under water, sucking up anything in its path, including fish, frogs and lizards. Fair weather waterspouts grow from the ocean up, created by the sudden convergence of smooth and choppy seas. Swirling water is pulled upward by rising air currents, without the help of a major storm system.

While fair weather waterspouts are weak and rarely cause damage, tornadic waterspouts have torn apart ships at sea. Famed waterspout researcher Joseph Golden believes many so-called 'Bermuda Triangle' disappearances are caused by killer waterspouts.

The walls of a waterspout are semi-transparent, since they are made of windswept water, not dirt and debris

Water world
You know you're in trouble when your street looks more like a river than a road

Floods

After the rains, the deluge

When you think of killer weather, you picture tsunami-battered coasts or twisting black tornadoes. But one of the deadliest weather phenomena worldwide is flooding. Flash floods – where small rivers and creeks swell without warning to raging torrents – are the number one weather-related killer in the United States. Flash floods can happen almost anywhere. In cities, there often isn't enough green space to absorb the runoff from a severe storm. This can overwhelm drainage systems, causing flash floods in low-lying areas.

In the mountains, a sudden torrential downpour can feed hundreds of small streams that merge in a single river valley. The result can be dramatic and deadly, creating a wall of churning water – five to ten metres of mud, rocks and debris – that wipes out everything in its path. Violent hurricane winds – gusting over 135kph (155mph) in some cases – can push a mound of water in front of the hurricane called a storm surge. During Hurricane Katrina, powerful surges breached the levee system, causing widespread destruction by flooding.

The 2007 floods in the UK were an example of river flooding caused by sustained, powerful rains. Over the course of 12 hours, parts of northeast England received a sixth of their annual rainfall, swallowing whole towns in swollen rivers.

HOW IT WORKS

FORCES OF NATURE

Discover Earth's natural forces

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Discover the Earth's amazing climates

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Find out what jet streams actually do

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How do these freakishly large waves appear?

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Why do these blinding flashes and rumbles occur?

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FORCES OF NATURE

© Andrew Mandemaker 2006

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Mount Herschel in Antarctica, which has been affected by global warming

© Andrew Mandemaker 2006

Earth's extreme climates

From dry, polar deserts to wet, hot rainforests and everything in between, Earth has some amazing extreme climates

Climate goes far beyond weather. It explains why there are such predictably disparate regions on the Earth and such wide variations in things like temperature, precipitation, humidity, wind, vegetation and plant life. There are a lot of different factors that play into the different climates present on our planet, and they work together in a complex way. One is the differences in how air circulates around the Earth. Depending on where you are located, you are in the path of a different wind belt or cell, with its own unique characteristics. They are considered the 'weathermakers' for the latitudes they occupy, as they both affect and are affected by temperatures on the Earth's surface.

Each of the five main lines of latitude – Arctic, Tropic of Cancer, the equator, Tropic of Capricorn and the Antarctic – also have a big impact on the climate in which you live. Most areas near the equator are hot, as the Sun is directly overhead with very little variation in temperature. As you move outwards on either side of the equator, temperatures can vary widely in part because the proximity of the Sun changes more drastically with the Earth's tilt and rotation. Once you reach the Poles, we're back to extremes, with temperatures that are consistently cold due to the distance from the Sun.

Topography also affects climate, and can supersede other factors. One striking example of this is California, which boasts several major different types of climate all in one state (some of which even have sub-climates). There is a Mediterranean

THE STATS
EARTH'S CLIMATE RECORDS

TOP TEMP	58°C
FASTEST TEMP DROP	27.2°C in 15 min
TOP RAINFALL	22,987mm
MOST YEARS WITHOUT RAIN	>20million
TOP WIND SPEED	~485km/h
LOWEST TEMP	-89.2°C

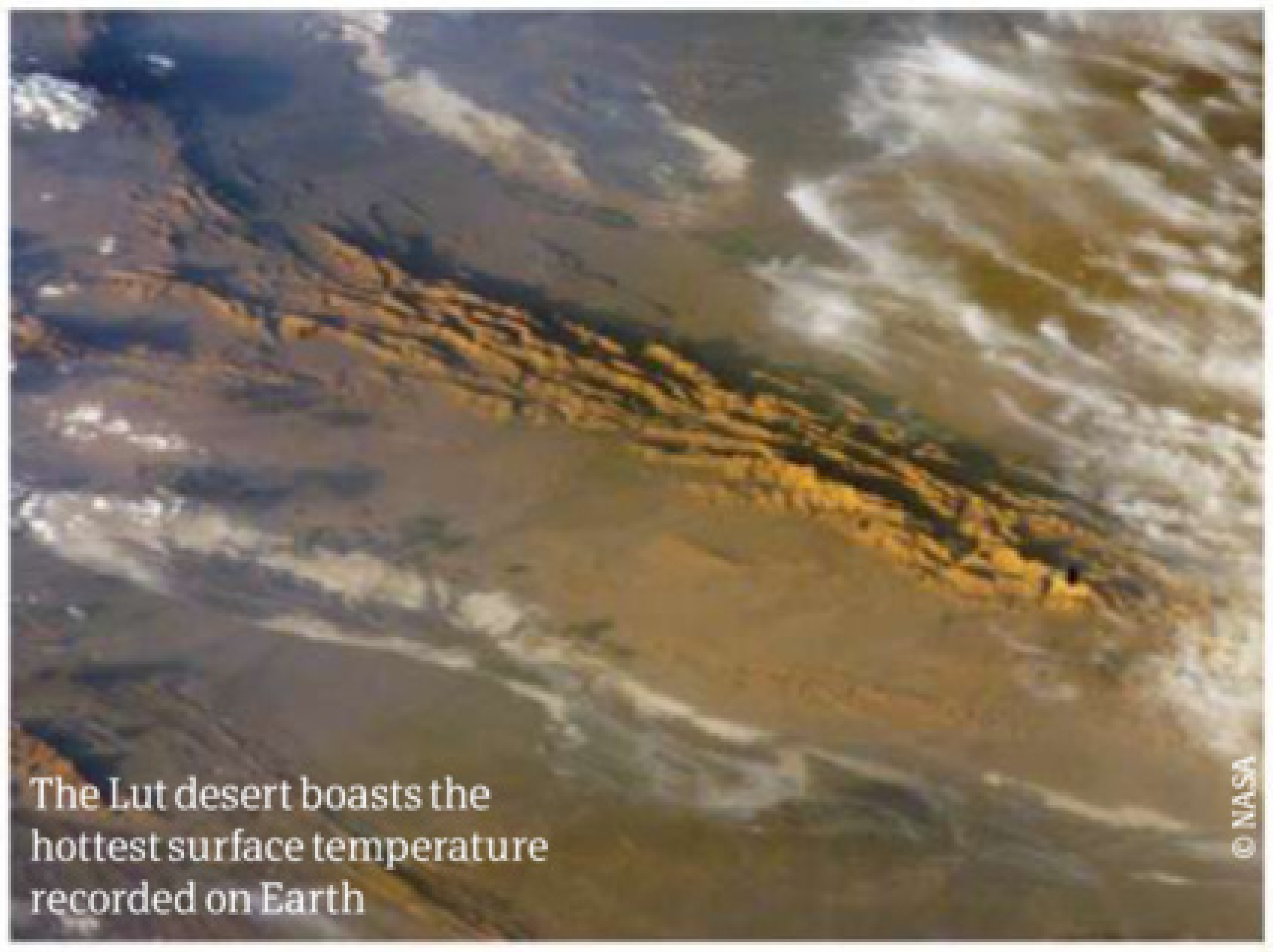
DID YOU KNOW? *Most extreme climate claims are disputed, due to variations in instrument accuracy and possible human error*

Atmospheric circulation

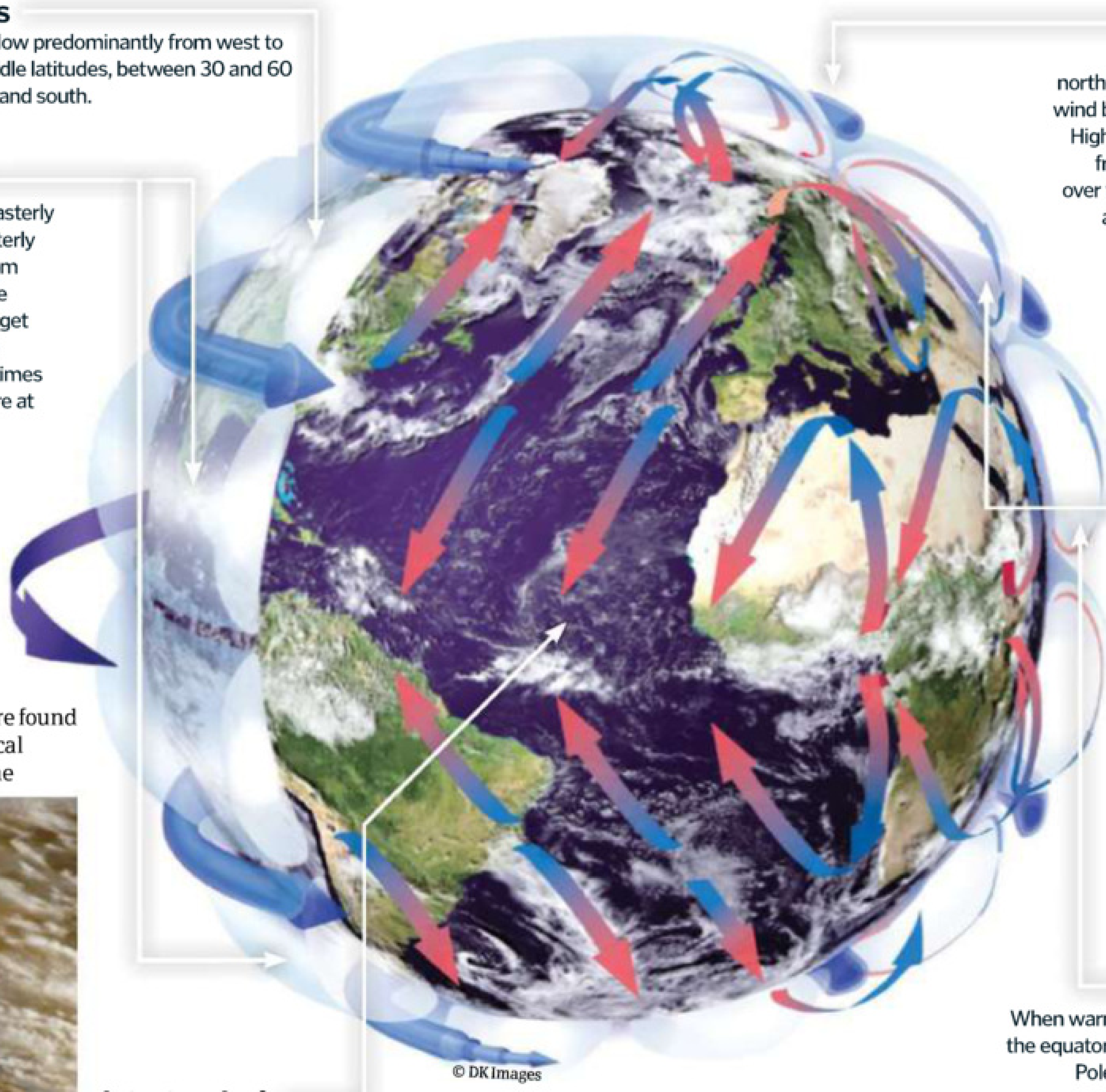
Atmospheric circulation is the way that the Sun's energy is dispersed across the Earth's surface. This large-scale air movement behaves in predictable patterns and follows specific cycles, creating different climates across the globe.

© NASA

The Doldrums are found in the intertropical convergence zone


The Lut desert boasts the hottest surface temperature recorded on Earth

© NASA


© DK Images

Westerlies
These winds blow predominantly from west to east in the middle latitudes, between 30 and 60 degrees north and south.

Trades
These north-easterly and south-easterly winds blow from their respective directions and get stronger in the winter during times of high pressure at the Poles.

Intertropical convergence zone
This area in between the various types of prevailing winds is very calm, with little to no wind.

Polar cell
The Polar cells are the northern and southernmost wind belts circling the Earth. High-pressure areas come from cold air circulating over the Poles, which heats and rises as they move outwards and create low-pressure areas.

Ferrel cell
Unlike the other cells, the Ferrel cell is not a closed loop. It is known as the 'zone of mixing', where the air from the Polar cells and Hadley cells converge.

Hadley cell
When warm, humid air rises near the equator, it travels towards the Poles and descends into a low-pressure area.

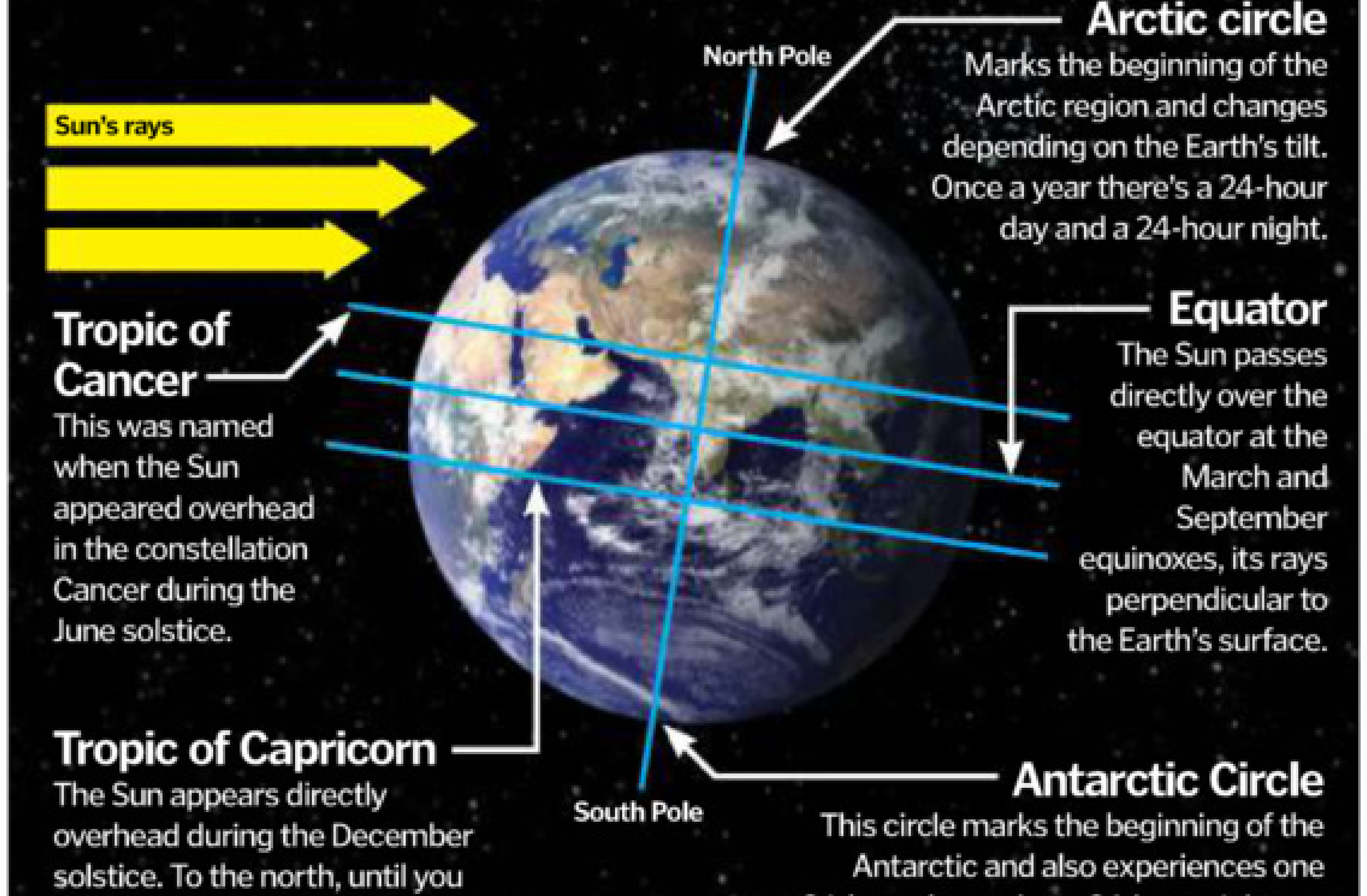
climate along the coast and in some of the interior valleys. A desert climate is present in dry valleys and mountain ranges. Other areas of high elevation have more temperate climates and vary depending on proximity to the ocean. California even has areas of steppe, a type of grassland. High temperatures across the state can reach 38°C (100°F) and lows can get down to -11°C (12°F). Thanks to its coast and the Andes, the country of Chile can also boast a number of different climates within its borders. Both California and Chile have numerous examples of micro-climates – areas where the climate can vary widely within square kilometres, thanks to differences in topography.

The Earth has undergone extreme climate shifts in its history, one such being the ice ages. Ice ages are periods when the temperature of the planet as a whole has gone down enough to create more alpine ice and polar ice sheets. In the Seventies many scientists speculated that we could be headed for another ice age. However, today the prevailing theory is that the Earth will experience a climate change due to global warming. While believers in the next ice age did not specify human involvement, global warming theorists point to an increase in greenhouse gases as a cause for rising temperatures around the globe. These gases absorb and emit radiation, and are a result of an increase in carbon dioxide in the Earth's atmosphere due to burning fossil fuels.

Another possible cause for climate change is deforestation, which has already affected climates in areas such as rainforests. There is a general consensus among the scientific community that the Earth's surface temperatures increased by 0.74°C (1.33°F) during the last century. The possibility of overall climate change to the Earth as a whole, however, remains controversial among the general public.

Changes in latitudes, Changes in attitudes

Latitude – whether you're north or south of the equator – has a huge impact on a region's climate. At the equator and the poles are the most extreme temperatures: very hot due to a lot of incident sunlight, or very cold due to a low amount of sunlight. The 'in between' areas, or 'middle' latitudes, generally have definitive seasons and wider ranges in temperature.



Arctic circle
Marks the beginning of the Arctic region and changes depending on the Earth's tilt. Once a year there's a 24-hour day and a 24-hour night.

Tropic of Cancer
This was named when the Sun appeared overhead in the constellation Cancer during the June solstice.

Equator
The Sun passes directly over the equator at the March and September equinoxes, its rays perpendicular to the Earth's surface.

Tropic of Capricorn
The Sun appears directly overhead during the December solstice. To the north, until you reach the Tropic of Cancer, is the tropical region.

Antarctic Circle
This circle marks the beginning of the Antarctic and also experiences one 24-hour day and one 24-hour night per year at the solstices.

Climate zones

The Earth's climates can be classified into different zones that have similar conditions, vegetation, types of seasons and temperatures

Polar/tundra

Generally the tundra has one month with an average temperature of 0°C (32°F), but no months with an average high greater than 10°C (50°F). There is low rainfall and snowfall, and vegetation comprises dwarf shrubs, lichen and grasses.

Examples: Alaska, northern Canada and Russia, Greenland, Iceland and northern Scandinavia.

© Hannes Grobe 2007

Boreal/coniferous forest

Boreal/coniferous forests are usually in areas of higher elevation, between 900 metres (2,953 feet) and 1,300 metres (4,265 feet) above sea level. There is a high level of both rain and snowfall and very cold temperatures.

Examples: Uplands of New England, inland Canada and Alaska, northern Norway, much of northern Asia.

Mountain

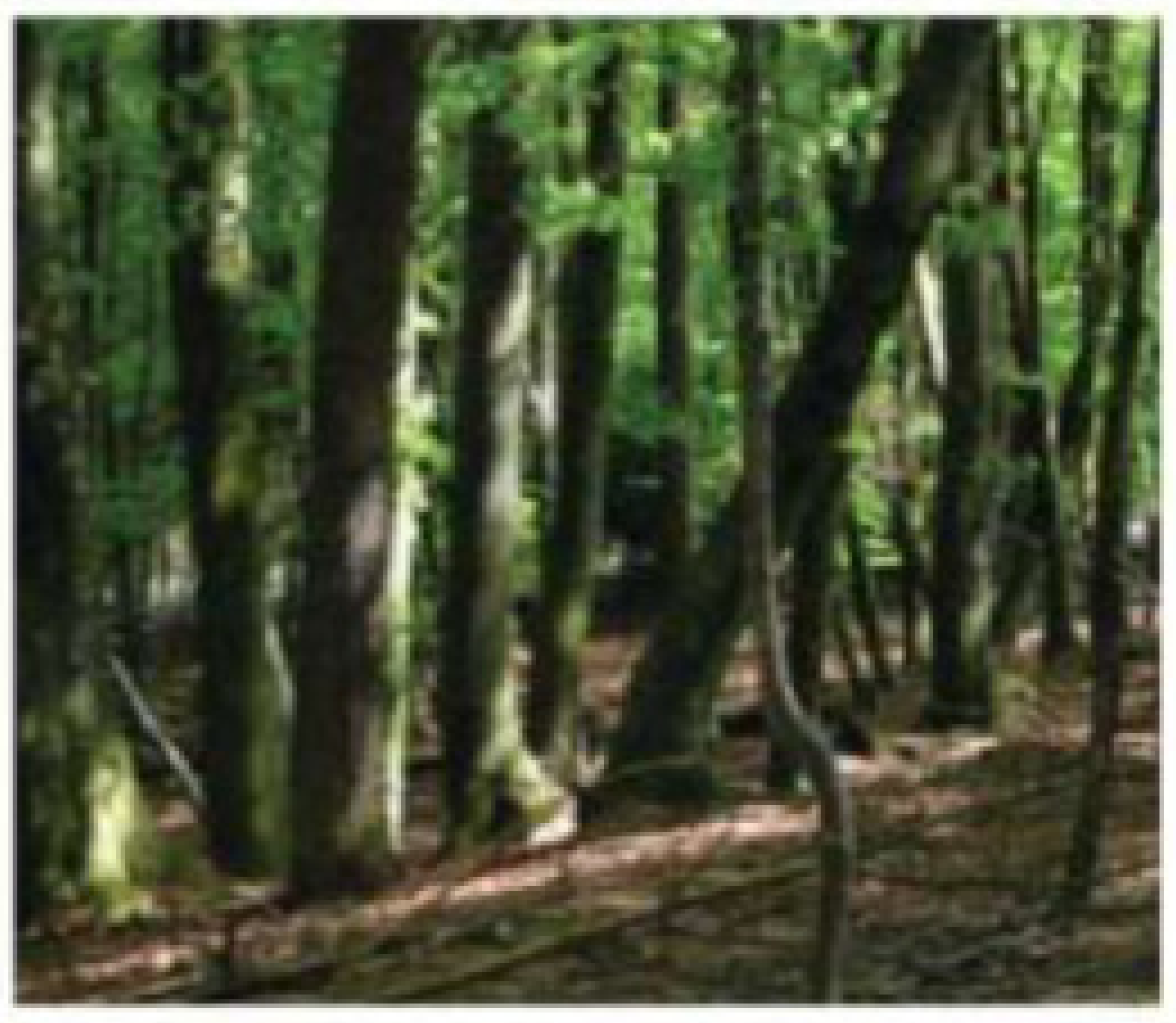
Mountain regions are above the tree line – the line at which trees stop growing due to extreme cold or dryness. High elevations mean colder temperatures because air expands when it rises. There are strong winds and there is usually a lot of snowfall.

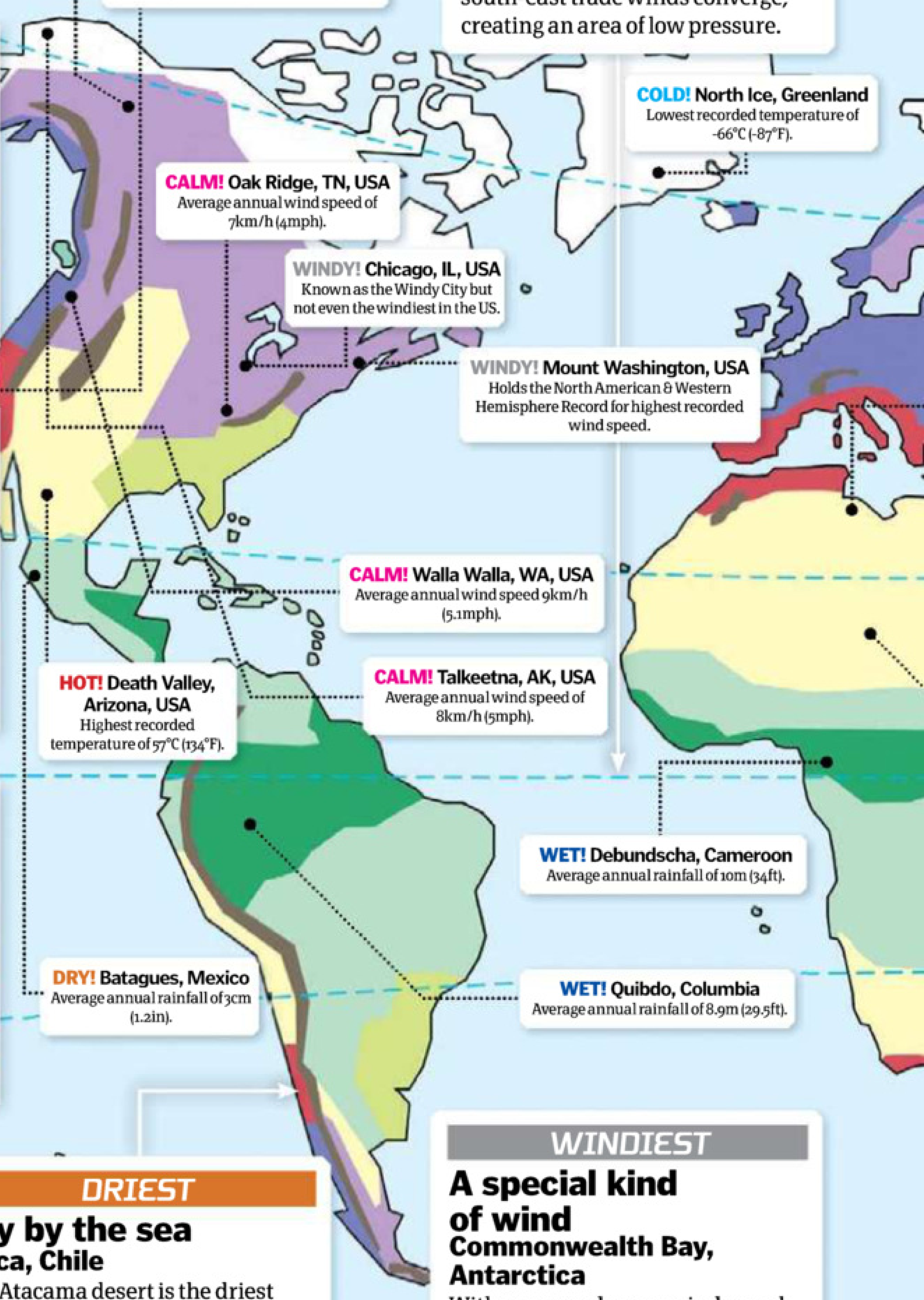
Examples: Rocky Mountains, Himalayas, Alps, Pyrenees, Andes.

Temperate/deciduous forest

As its name implies, this climate is very moderate, with distinct seasons. Summer highs can reach 32°C (90°F) and a winter lows can reach -1°C (30°F). Rainfall and snowfall can vary widely.

Examples: Eastern and western United States, Canada, Europe, West Asia.





COLD! Snag, Yukon, Canada
Lowest recorded temperature of -63°C (-81°F).

WET! Mount Waialeale, HI, USA
Average annual rainfall of 11m (36ft).

CALM! Oak Ridge, TN, USA
Average annual wind speed of 7km/h (4mph).

WINDY! Chicago, IL, USA
Known as the Windy City but not even the windiest in the US.

COLD! North Ice, Greenland
Lowest recorded temperature of -66°C (-87°F).

WINDY! Mount Washington, USA
Holds the North American & Western Hemisphere Record for highest recorded wind speed.

CALM! Walla Walla, WA, USA
Average annual wind speed 9km/h (5.1mph).

HOT! Death Valley, Arizona, USA
Highest recorded temperature of 57°C (134°F).

CALM! Talkeetna, AK, USA
Average annual wind speed of 8km/h (5mph).

WET! Debundscha, Cameroon
Average annual rainfall of 10m (34ft).

DRY! Batagues, Mexico
Average annual rainfall of 3cm (1.2in).

WET! Quibdo, Columbia
Average annual rainfall of 8.9m (29.5ft).

STILLEST

Rising air

The Doldrums

Sailors travelling through this region near the equator, known as the intertropical convergence zone (ITCZ), called it 'The Doldrums' because the air is so still. Rather than blowing as wind, air rises due to convection as it is heated by the Sun. This is generally located about five degrees north and south of the equator, but can move as much as 45 degrees in either direction. The ITCZ is where the north-east and south-east trade winds converge, creating an area of low pressure.

DRIEST

Dry by the sea

Arica, Chile

The Atacama desert is the driest region on Earth, and Arica is the driest city. There are regions that have not received rainfall in tens of millions of years. Arica itself receives about 0.75 millimetres (0.03 inches) per year, and once went a span of 173 months without rainfall. Despite this, Arica's average annual high is only around 27°C (80°F).

WINDIEST

A special kind of wind

Commonwealth Bay, Antarctica

With an annual mean wind speed of over 80km/h (50 mph) and winds regularly topping 240km/h (149 mph), this is the windiest place on Earth. Katabatic wind also occurs, where cold air rushes down a steep, ice shield from the rocky point of Cape Denison towards the water.

DID YOU KNOW?

© NASA

Extreme climate on other planets

Mars is the most Earth-like when it comes to climate, with a summer high of 20°C (68°F). However, the average daytime temperature is -50°C (-58°F). There's also the little problem of no air, very little surface pressure and no magnetic field.

DID YOU KNOW? *Increases in global temperatures can result in more extreme weather events, like tornadoes and hurricanes*

HOTTEST

Toasted wheat

Lut desert, Iran

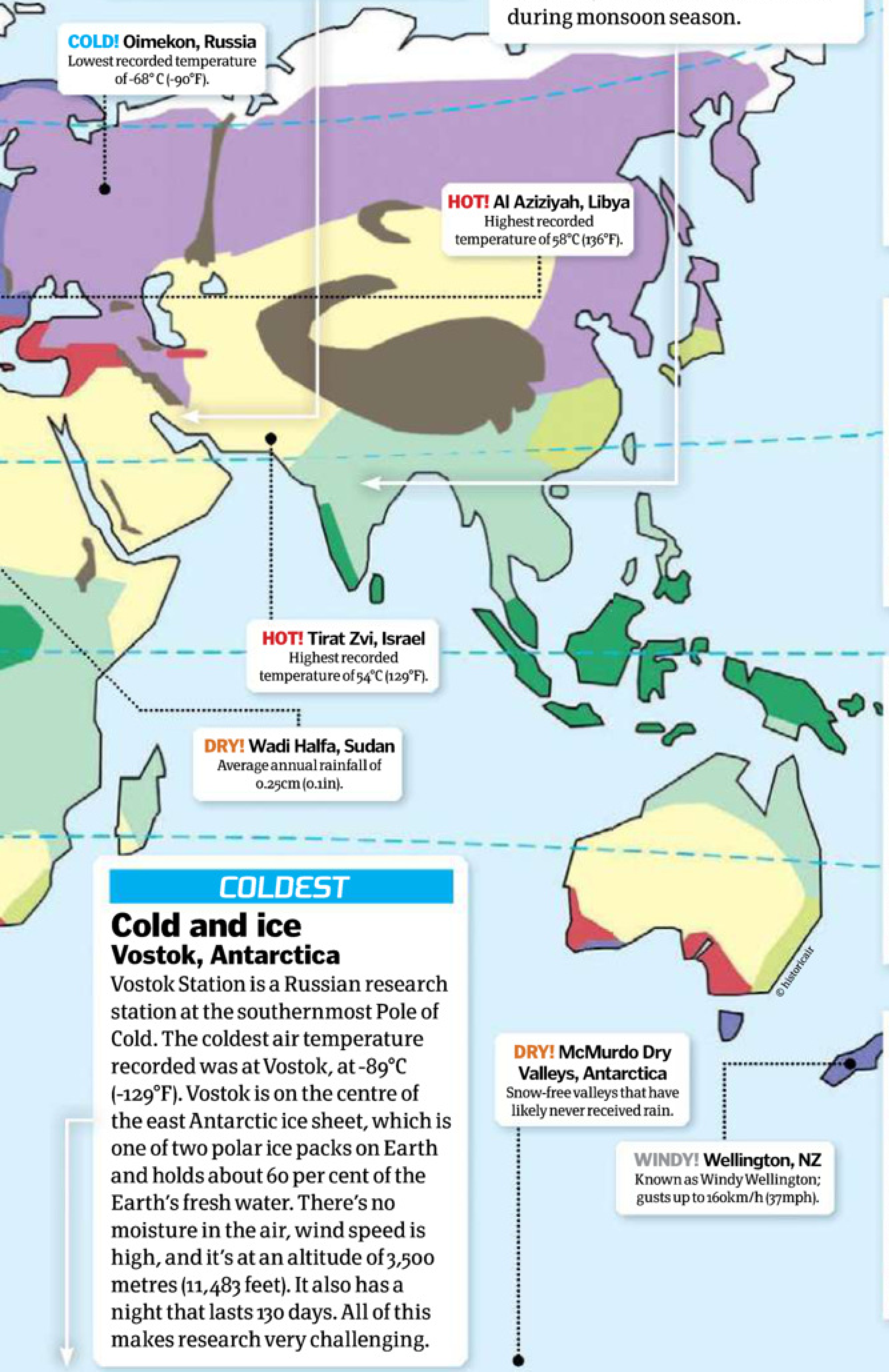
This large desert basin comprises mostly salt, sand and rock. Its title as the hottest place on Earth is in dispute, but according to NASA satellite measurements in 2005 the average land temperature is 71°C (159°F). Surrounded by mountains, it is considered a dry drainage basin. One area is known as Gandom Beriyan, Persian for 'toasted wheat', due to a story that spilled wheat scorched in just a few days.

WETTEST

Water, water!

Mawsynram, India

The wettest place actually varies between Mawsynram and the nearby city of Cherrapunji, with a difference of less than 1,000 milimetres of annual rainfall. Mawsynram in north-east India has an average annual rainfall of nearly 12 metres (39 feet). Mawsynram is in the Khsai Hills and about 1,400 metres (4,593 feet) above sea level. Air blowing in from nearby plains cools as it rises, trapping moisture in clouds, which release their rain during monsoon season.


© historicair

COLD! Oimekon, Russia
Lowest recorded temperature of -68° C (-90°F).

HOT! Al Aziziyah, Libya
Highest recorded temperature of 58°C (136°F).

HOT! Tirat Zvi, Israel
Highest recorded temperature of 54°C (129°F).

DRY! Wadi Halfa, Sudan
Average annual rainfall of 0.25cm (0.1in).

DRY! McMurdo Dry Valleys, Antarctica
Snow-free valleys that have likely never received rain.

WINDY! Wellington, NZ
Known as Windy Wellington; gusts up to 160km/h (37mph).

COLDEST

Cold and ice

Vostok, Antarctica

Vostok Station is a Russian research station at the southernmost Pole of Cold. The coldest air temperature recorded was at Vostok, at -89°C (-129°F). Vostok is on the centre of the east Antarctic ice sheet, which is one of two polar ice packs on Earth and holds about 60 per cent of the Earth's fresh water. There's no moisture in the air, wind speed is high, and it's at an altitude of 3,500 metres (11,483 feet). It also has a night that lasts 130 days. All of this makes research very challenging.

Mediterranean

Although it is generally centred around the Mediterranean basin, this climate exists in other parts of the world that are near warm bodies of water. There are cool, wet winters and hot, dry summers due to subtropic air pressures.

Examples: Mediterranean, California, western and south Australia, parts of central Asia.

Desert

The main defining characteristic of deserts is the lack of precipitation – most get less than 250mm (10in) per year. Many are so dry that there is a moisture deficit and very little vegetation. Deserts are thought of as hot and sandy, but there are polar deserts as well.

Examples: Arabian, Sahara, Gobi, Kalahari, Antarctic, Arctic.

Temperate grassland

These areas have no large trees, just grasses and shrubs. There are wide variations in temperature. Winter lows can reach -40° C (-40°F) and summer highs can go up to 38°C (100°F). Rainfall averages 50cm (20in) per year.

Examples: Prairies of North America, steppes of Europe, pampas of South America.

Tropical grassland/savannah

Savannahs have grassy areas with widely spaced tree cover. There is generally just one rainy season that can produce up to 150cm (59in) of precipitation over the space of as little as a few weeks. Average temperature is 30°C (86°F).

Examples: African savanna, northern Australia, southern United States.

Tropical rainforest

Tropical rainforests are found within 28 degrees north or south of the Equator. Annual rainfall is about 200cm (80in) and the average temperature is always above 20°C (68°F) no matter what time of year. There is a dense tree canopy and little undergrowth.

Examples: Africa, Asia, Australia, Central America, South America.

How do jet streams work?

They're a vital component in regulating global weather, but what do jet streams actually do?

Jet streams are currents of fast-moving air found high in the atmosphere of some planets. Here on Earth, when we refer to 'the jet stream', we're typically talking about either of the polar jet streams. There are also weaker, subtropical jet streams higher up in the atmosphere, but their altitude means they have less of an effect on commercial air traffic and the weather systems in more populated areas.

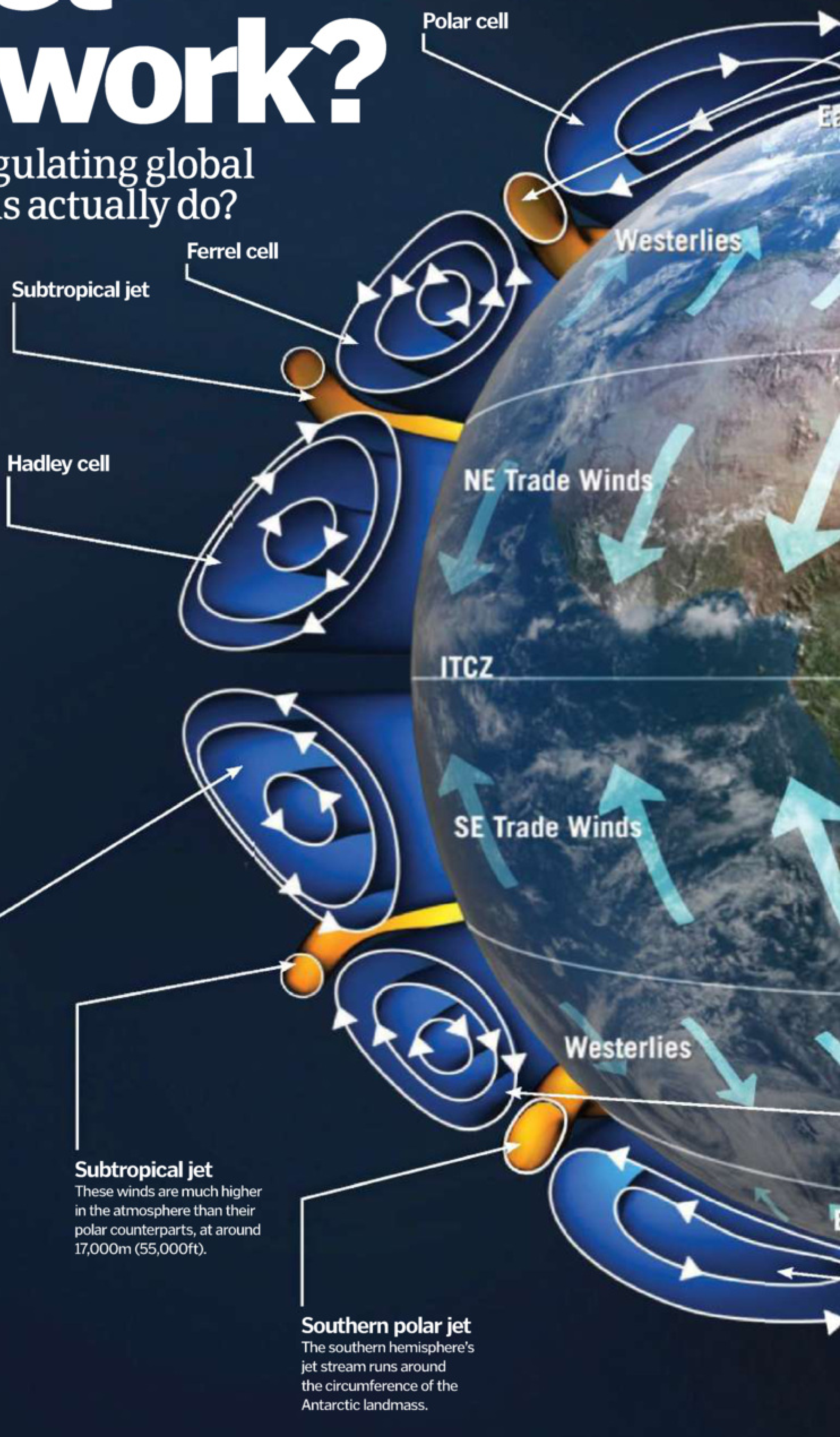
The northern jet stream travels at about 161-322 kilometres (100-200 miles) per hour from west to east, ten kilometres (six miles) above the surface in a region of the atmosphere known as the tropopause (the border between the troposphere and the stratosphere). It's created by a combination of our planet's rotation, atmospheric heating from the Sun and the Earth's own heat from its core creating temperature differences and, thus, pressure gradients along which air rushes.

In the northern hemisphere, the position of the jet stream can affect the weather by bringing in or pushing away the cold air from the poles. Generally, if it moves south, the weather can turn wet and windy; too far south and it will become much colder than usual. The reverse is true if the jet stream moves north, inducing drier and hotter weather than average as warm air moves in from the south.

In the southern hemisphere, meanwhile, the jet stream tends to be weakened by a smaller temperature contrast created by the greater expanse of flat, even ocean surface, although it can impact the weather in exactly the same way as the northern jet stream does.

Earth's jet streams

A closer look at some of the invisible phenomena that play a major role in our planet's climate



Hadley cell
This atmospheric cell is partly responsible for the deserts and rainstorms in the tropics.

Subtropical jet
These winds are much higher in the atmosphere than their polar counterparts, at around 17,000m (55,000ft).

Southern polar jet
The southern hemisphere's jet stream runs around the circumference of the Antarctic landmass.

Winds of change

Currents in the jet stream travel at various speeds, but the wind is at its greatest velocity at the centre, where jet streaks can reach speeds as fast as 322 kilometres (200 miles) per hour. Pilots are trained to work with these persistent winds when flying at jet stream altitude, but wind shear is a dangerous phenomenon that they must be ever vigilant of. This is a sudden, violent change in wind direction and speed that can happen in and around the jet stream, affecting even winds at ground level. A sudden gust like this can cause a plane that's taking off/landing to crash, which is why wind shear warning systems are equipped as standard on all commercial airliners.

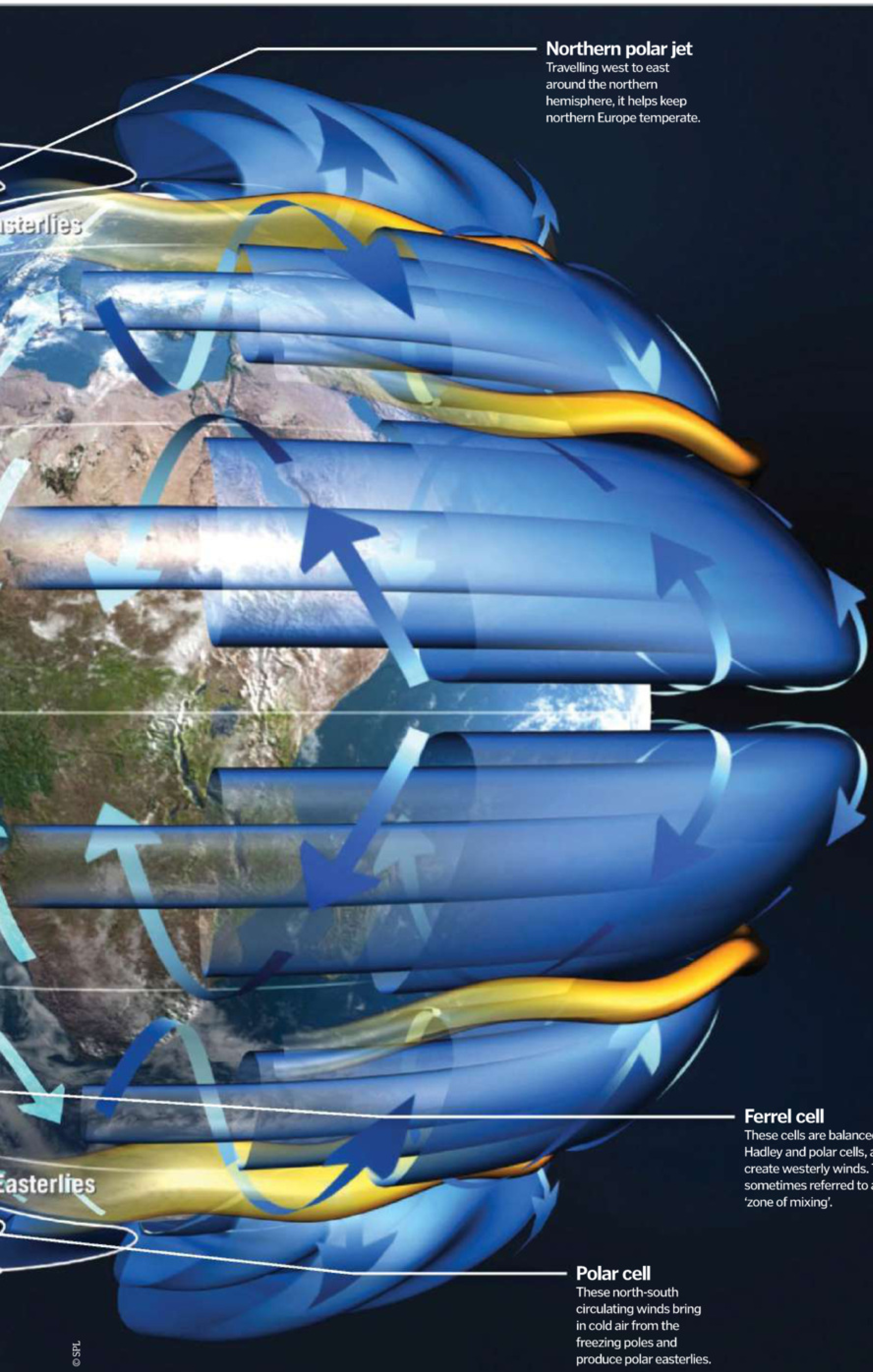
RECORD BREAKERS
BLOW ME DOWN!

372km/h

FASTEST WIND IN THE WEST

The highest terrestrial wind speed ever recorded was in April 1934 on Mount Washington, USA, where a very strong jet stream descended onto the 1,917m (6,288ft) summit.

DID YOU KNOW? Mount Everest is so high that its 8,848m (29,029ft) summit actually sits in a jet stream

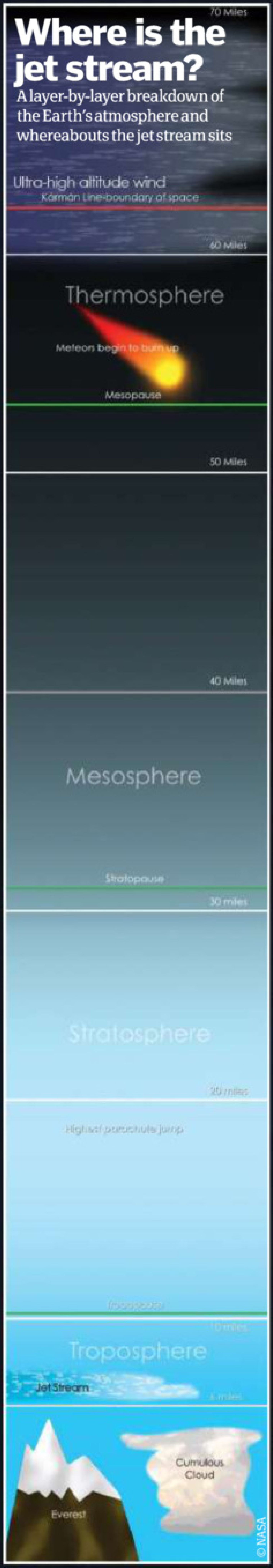


Northern polar jet
Travelling west to east around the northern hemisphere, it helps keep northern Europe temperate.

Ferrel cell
These cells are balanced by the Hadley and polar cells, and create westerly winds. They are sometimes referred to as the 'zone of mixing'.

Polar cell
These north-south circulating winds bring in cold air from the freezing poles and produce polar easterlies.

© SPL



Where is the jet stream?

A layer-by-layer breakdown of the Earth's atmosphere and whereabouts the jet stream sits

© NASA

What causes rogue waves?

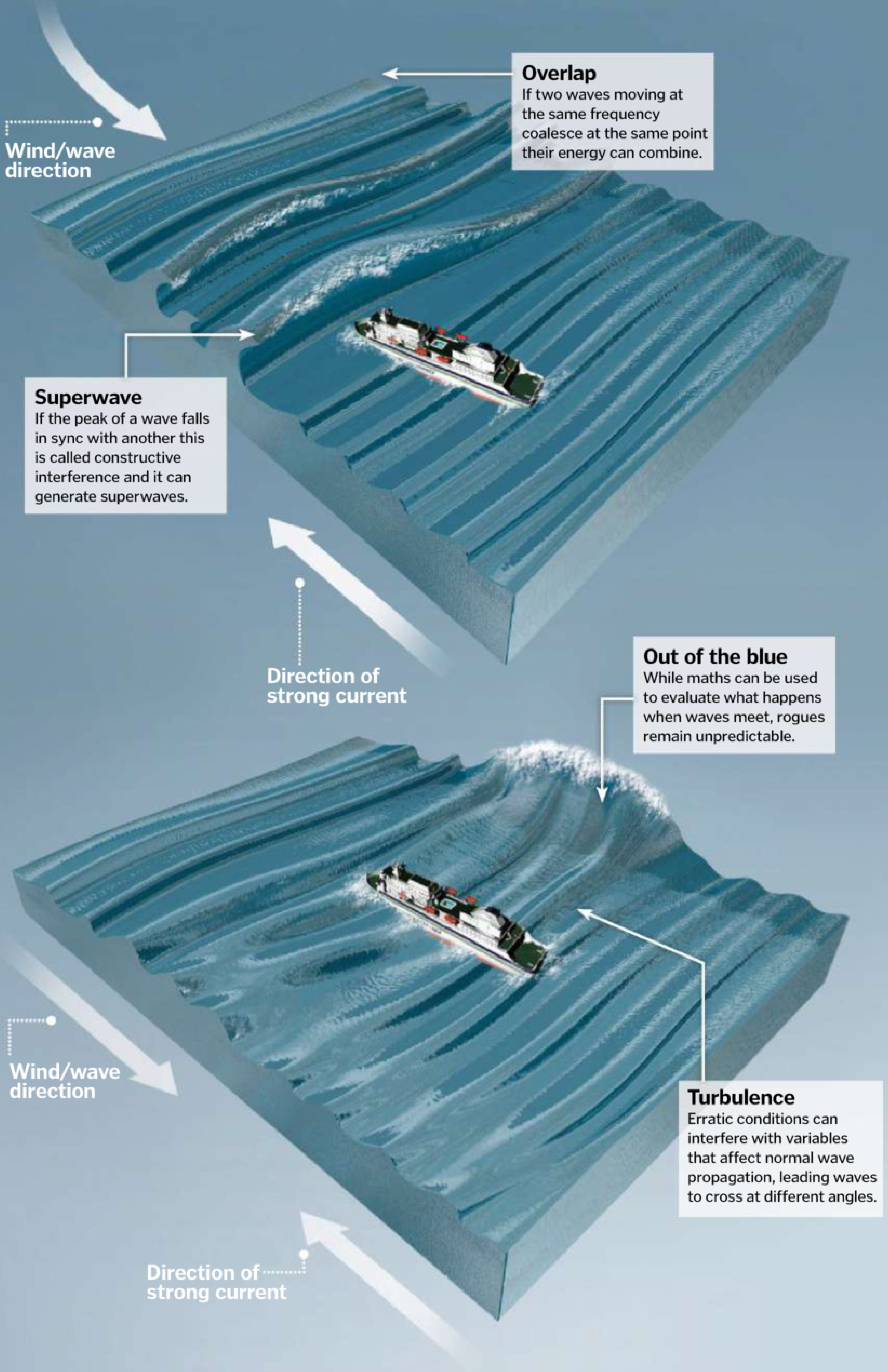
What are these freakishly giant waves that appear as if from nowhere far out at sea?

Maritime history has long told of infeasibly tall waves that strike suddenly during calm seas and topple boats. And yet to date little is understood about what causes these mystery waves. An ESA project confirmed the existence of these mammoth swells when it recorded ten waves all over 25 metres (80 feet) during a three-week period in 2001.

A rogue wave is defined as being around three times the average height of the other waves around it. So they needn't actually be massive – just surprisingly large compared with the general sea state. Their very nature makes it difficult to predict or pinpoint their exact cause as factors such as water depth, currents and many other variables will all affect the propagation and development of a single wave.

Energy can be exchanged between multiple waves to generate abnormally large ones. For example, when a small, fast wave catches up with a large, slow wave, the energy of both can combine to create a single, high-intensity mutant wave.

There are also specific regions of Earth more prone to rogues. The interaction of surface waves and the Agulhas Current near South Africa's east coast, for example, is thought to breed giant waves that propagate from east to west. Environmental engineers at the University of Wisconsin-Madison discovered that when fast waves from one direction interacted with the strong currents moving in the opposite direction, a wave could rise up and 'climb' the current's wall.



Overlap
If two waves moving at the same frequency coalesce at the same point their energy can combine.

Superwave
If the peak of a wave falls in sync with another this is called constructive interference and it can generate superwaves.

Out of the blue
While maths can be used to evaluate what happens when waves meet, rogues remain unpredictable.

Turbulence
Erratic conditions can interfere with variables that affect normal wave propagation, leading waves to cross at different angles.

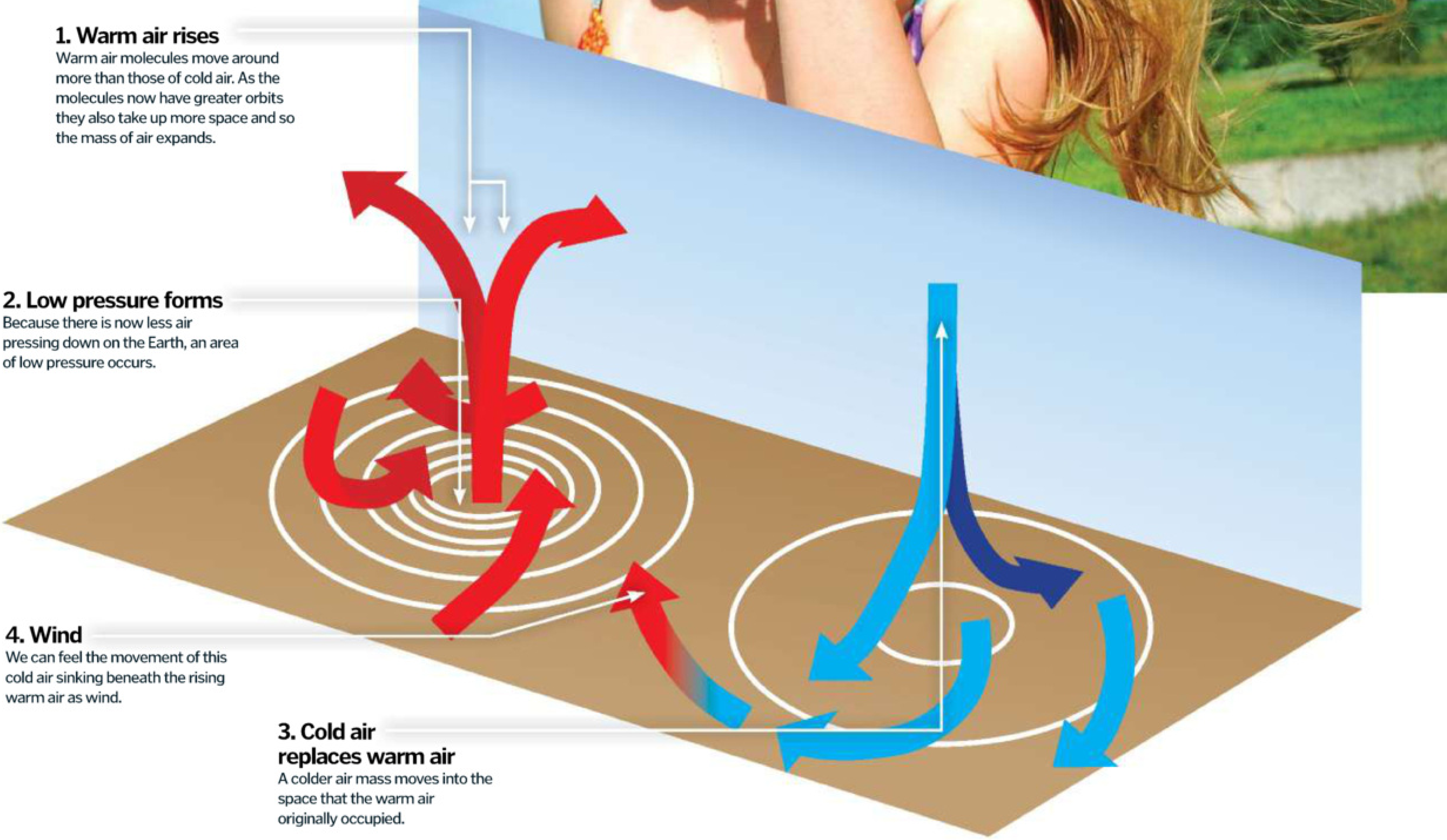
© Science Photo Library

The science of wind

It's invisible but we see and feel its effects every day, so just what is wind?

Winds are the air currents in Earth's atmosphere that move due to changes in pressure. When the Sun's energy heats the surface of the Earth, the air mass overhead becomes warmer and less dense, which causes it to expand and rise. Air masses typically cover millions of square kilometres. Because there is now less air pressing down on the Earth, an area of low pressure develops. To maintain balance, the nearest mass of cooler, higher-pressure air automatically moves into the lower-pressure area to fill the gap. The movement of this air mass is wind. The greater the difference in air mass temperature, the more intense the wind blows. Remember, air always flows from an area of high pressure to an area of low pressure.

Low- and high-pressure zones



1. Warm air rises
Warm air molecules move around more than those of cold air. As the molecules now have greater orbits they also take up more space and so the mass of air expands.

2. Low pressure forms
Because there is now less air pressing down on the Earth, an area of low pressure occurs.

4. Wind
We can feel the movement of this cold air sinking beneath the rising warm air as wind.

3. Cold air replaces warm air
A colder air mass moves into the space that the warm air originally occupied.

Supercell thunderstorms

Why do those blinding flashes and ominous rumbles occur?

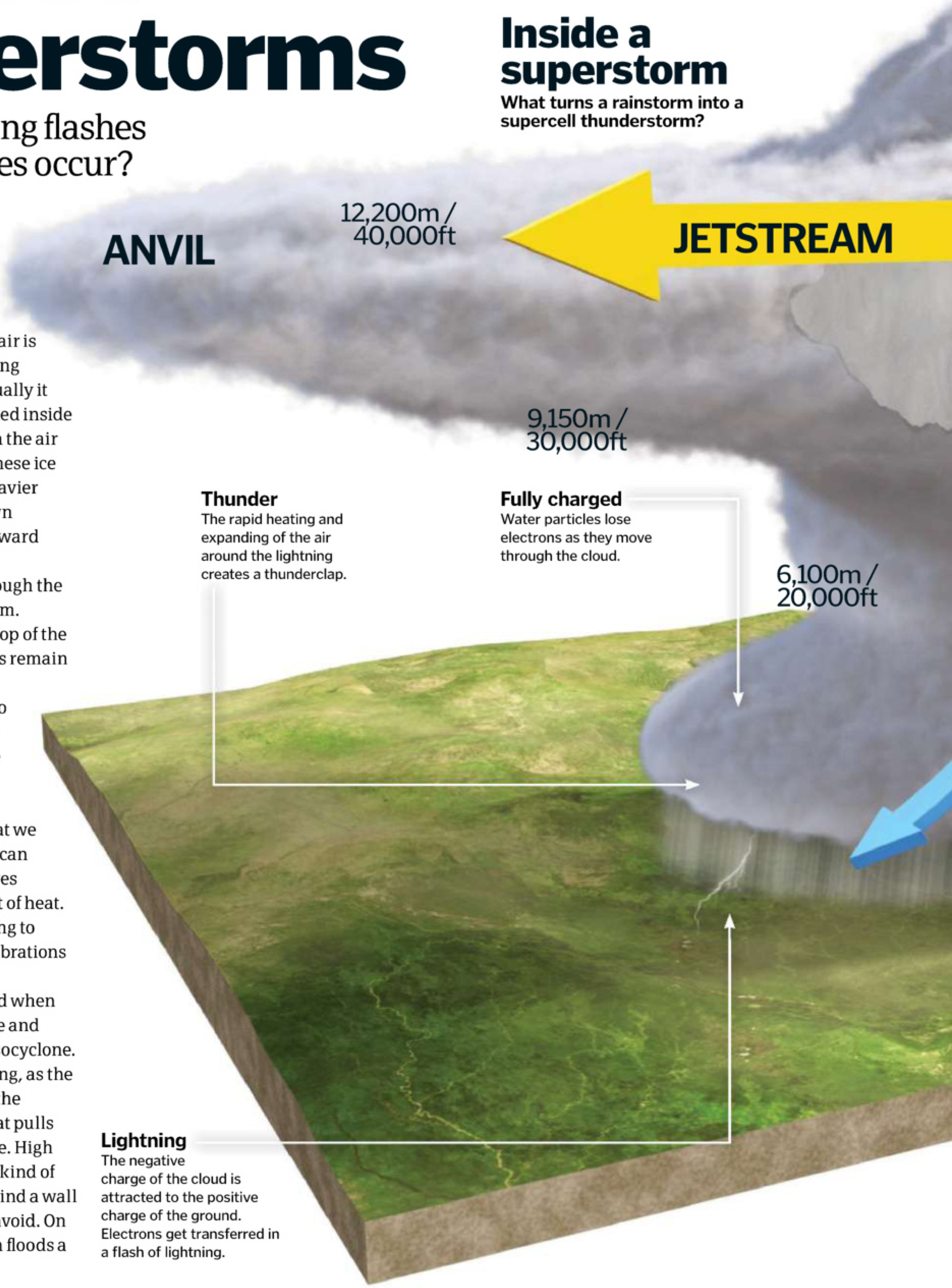
Thunderstorms are both spectacular and a bit scary, but what creates this awe-inspiring mix of rain, thunder and lightning? On warm days, hot air forms near the Earth's surface. As hot air is less dense than cold air, it rises, pushing through the colder air above it. Eventually it cools enough for the moisture contained inside the air to condense. As the moisture in the air turns to liquid, it forms ice crystals. These ice crystals are dense, so they become heavier than the updraft and begin to fall down through the cloud. As they descend toward Earth they thaw and become rain.

When the water particles move through the cloud, electrons are stripped from them. Positively charged particles sit at the top of the cloud and negatively charged particles remain at the bottom. This induces a positive charge on the Earth's surface below, so the clouds are desperate to hand over their spare electrons. Once the charge has built up, the electrons from the cloud power toward the ground, discharged as a spark of electricity that we see as a bolt of lightning. As lightning can travel at a breakneck 160,000 kilometres (100,000 miles) per hour, it creates a lot of heat. This causes the air around the lightning to expand extremely quickly, creating vibrations that we hear as thunder.

Supercell thunderstorms are formed when thunderstorms and high winds collide and combine, causing what is called a mesocyclone. This will often lead to a tornado forming, as the rapidly rotating wind combines with the updraft to create a weather system that pulls objects upward with tremendous force. High precipitation supercells are the worst kind of them all, as the tornado is hidden behind a wall of water, making it tricky to spot and avoid. On top of it all, the heavy rain makes flash floods a real risk.

Inside a superstorm

What turns a rainstorm into a supercell thunderstorm?

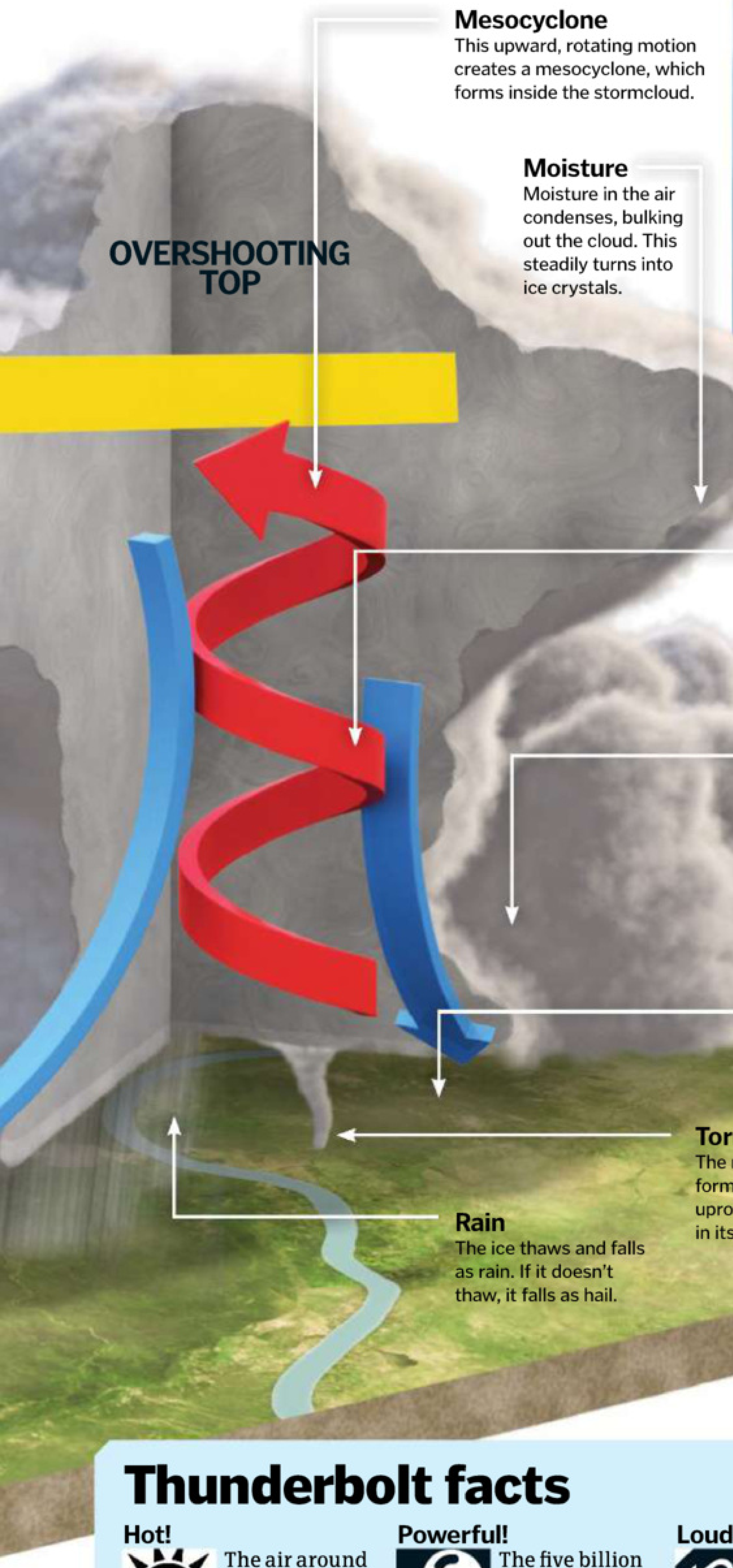


Thunder The rapid heating and expanding of the air around the lightning creates a thunderclap.

Fully charged Water particles lose electrons as they move through the cloud.

Lightning The negative charge of the cloud is attracted to the positive charge of the ground. Electrons get transferred in a flash of lightning.

DID YOU KNOW? *Supercell tornadoes can bring hail more than 1.9cm (0.75in) in diameter*



Mesocyclone
This upward, rotating motion creates a mesocyclone, which forms inside the stormcloud.

Moisture
Moisture in the air condenses, bulking out the cloud. This steadily turns into ice crystals.

Warm air rises
As warm air is denser than cold, it rises up through the atmosphere until it reaches the clouds.

High winds
If the storm meets high winds, the updrafts pull the wind around the cloud.

Warm air
The Earth and the air above it is warmed by the Sun.

Tornado
The mesocyclone can also form a tornado, which can uproot buildings and vehicles in its powerful vortex.

Rain
The ice thaws and falls as rain. If it doesn't thaw, it falls as hail.

The stormcloud of a supercell thunderstorm is an impressive sight

Different types of thunderstorm

Single cell storms
Single cell storms are the weakest kind. They usually last less than half an hour and don't cause much damage because there isn't much horizontal wind to push them along.

Multicell cluster storms
You will see multicell cluster storms more than any other. This is when several storm cells combine, acting at different times in the cycle, so as one stops raining, another begins. As they are all separate, though, strong tornadoes are rare in this type of storm.

Multicell line storm
A long line of storms is called a multicell line storm. It's also known as a squall line and forms when a group of storm clouds are led along a route by a strong, sustained gust of wind. Cold air on the outside of the system forces warm air rapidly upward, resulting in incredibly heavy downpours of rain.

Thunderbolt facts

Hot!
The air around lightning heats to a scorching 27,760°C (50,000°F). This is five times hotter than the surface of the Sun.

Powerful!
The five billion joules of energy in a single lightning bolt could fulfil a home's electricity needs for a whole year.

Loud!
Thunder can be as loud as 120dB. This is loud enough to be heard over the crashing guitars of a rock concert.

Fast!
70
Tornadoes can move at over 113km/h (70mph), which is as fast as the highest current speed limit on British motorways.

© The Art Agency; Dreamstime

How insects survive floods

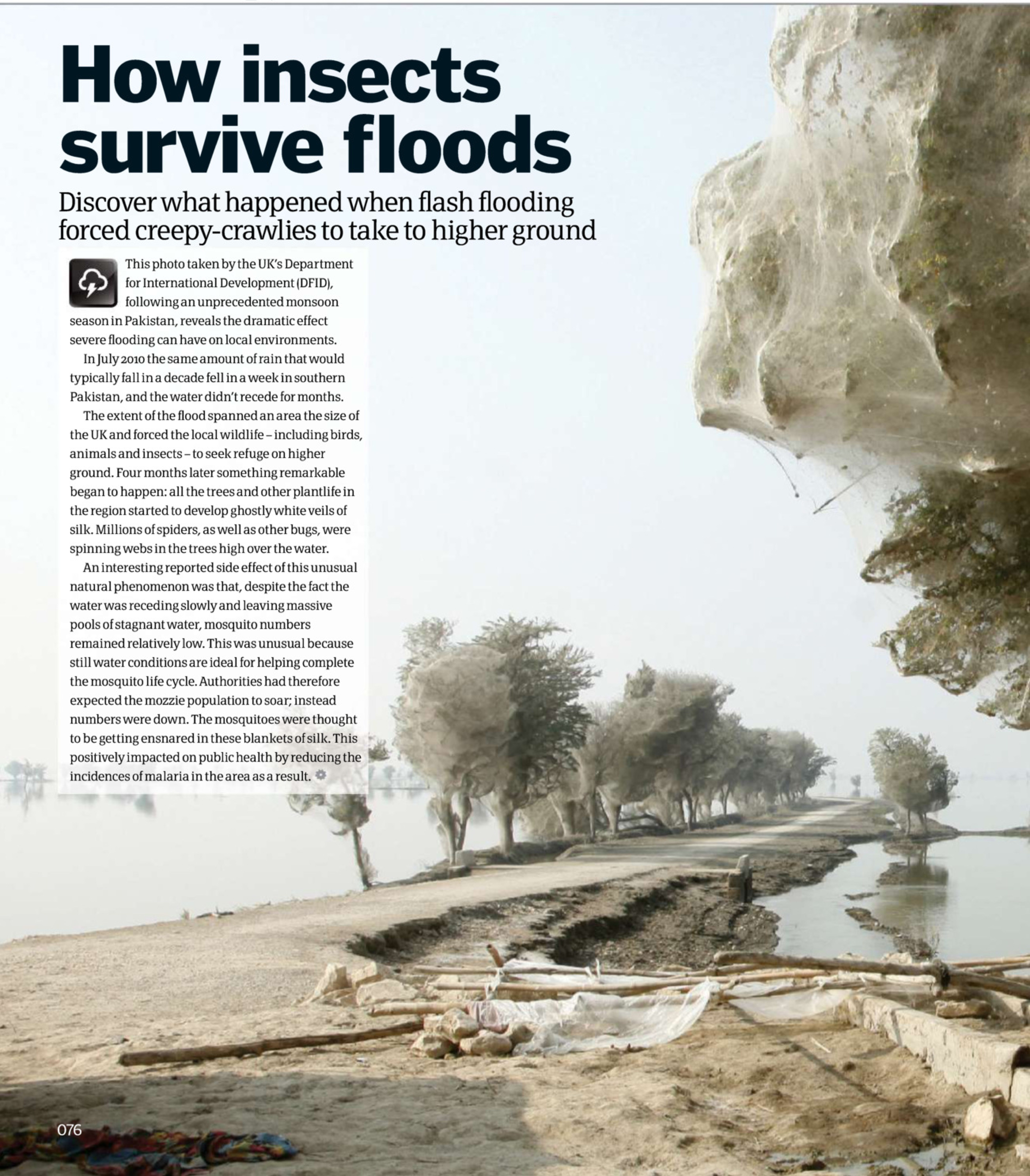
Discover what happened when flash flooding forced creepy-crawlies to take to higher ground

This photo taken by the UK's Department for International Development (DFID), following an unprecedented monsoon season in Pakistan, reveals the dramatic effect severe flooding can have on local environments.

In July 2010 the same amount of rain that would typically fall in a decade fell in a week in southern Pakistan, and the water didn't recede for months.

The extent of the flood spanned an area the size of the UK and forced the local wildlife – including birds, animals and insects – to seek refuge on higher ground. Four months later something remarkable began to happen: all the trees and other plantlife in the region started to develop ghostly white veils of silk. Millions of spiders, as well as other bugs, were spinning webs in the trees high over the water.

An interesting reported side effect of this unusual natural phenomenon was that, despite the fact the water was receding slowly and leaving massive pools of stagnant water, mosquito numbers remained relatively low. This was unusual because still water conditions are ideal for helping complete the mosquito life cycle. Authorities had therefore expected the mozzie population to soar; instead numbers were down. The mosquitoes were thought to be getting ensnared in these blankets of silk. This positively impacted on public health by reducing the incidences of malaria in the area as a result.



STRANGE BUT TRUE

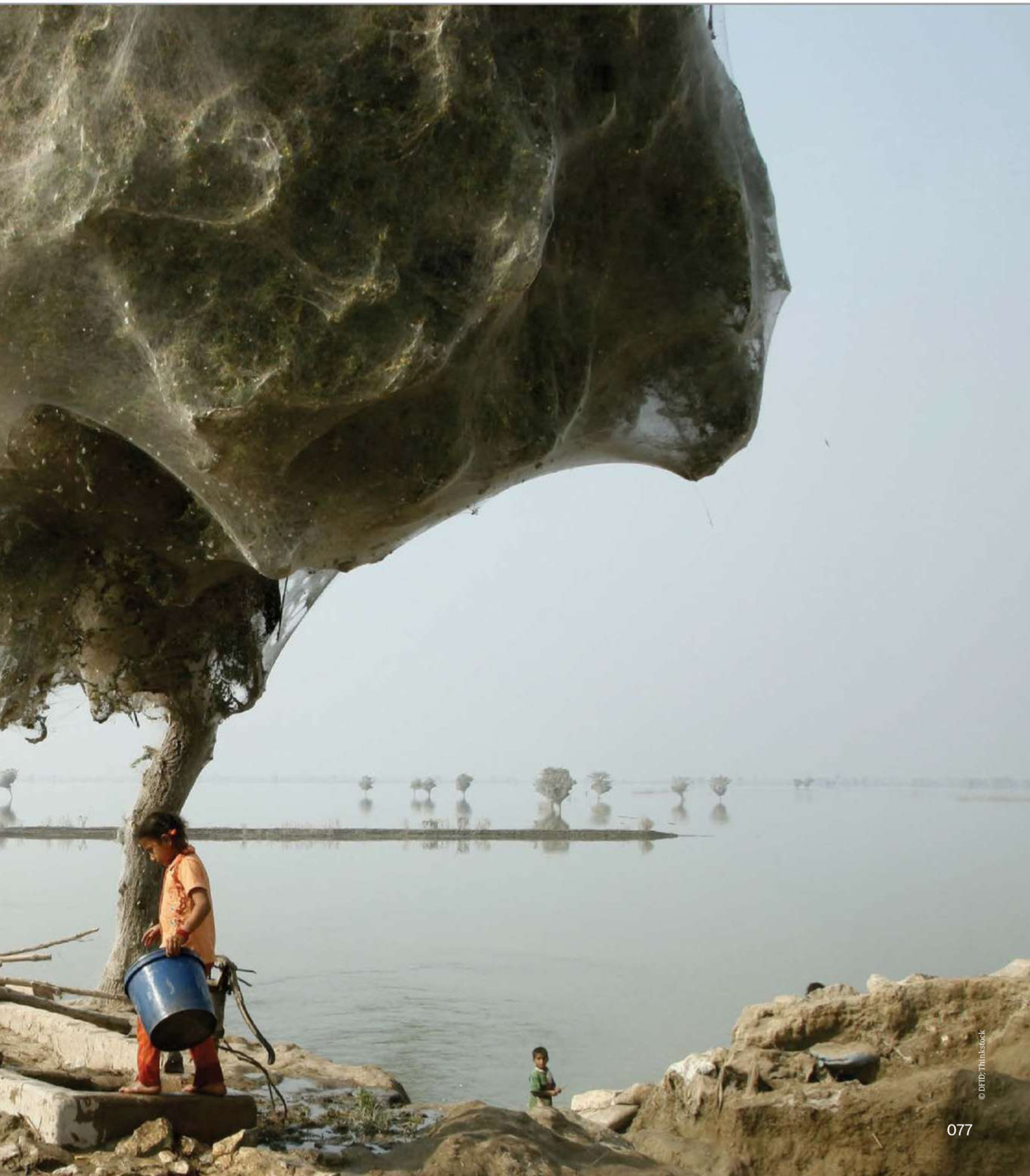
EIGHT-LEGGED ESCAPE ARTIST

How do spiders sometimes make a quick getaway?

A Ballooning B Paragliding C Diving

Answer:
Spiders can get airborne by spinning a single strand of silk and waiting for a breeze. When the velocity of upward air flow causes drag that exceeds the pull of gravity an arachnid can take off on the breeze, a phenomenon known as ballooning.

DID YOU KNOW? *A farm in Australia was also overrun when subterranean wolf spiders sought refuge from flood water*



© DFID; Thinkstock

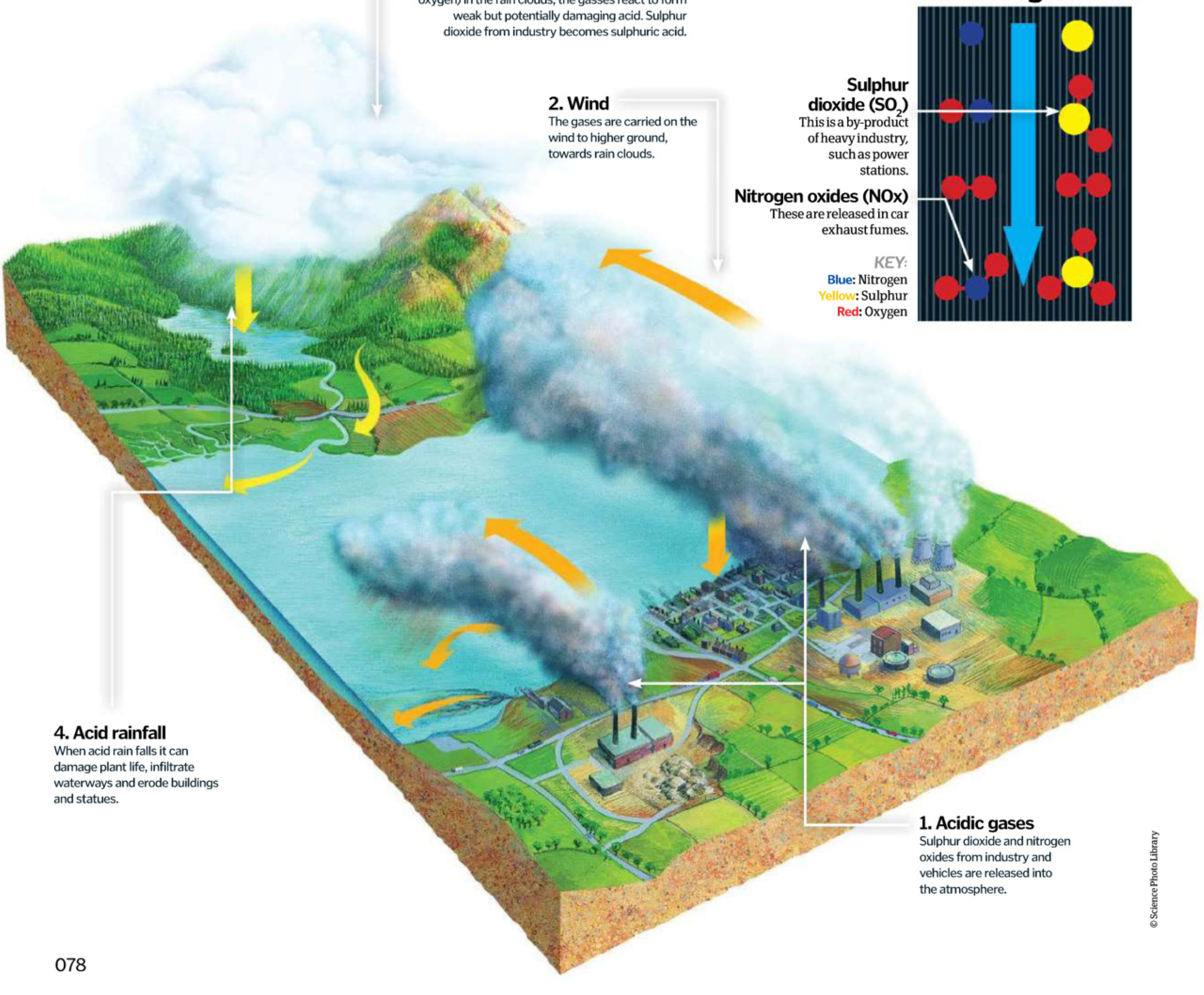
Where does acid rain come from?

We've all seen the effects of acid rain on limestone statues, but how does this damaging substance form?

All rainwater is a little bit acidic, because the carbon dioxide present in the atmosphere dissolves in water and forms carbonic acid. Stronger acid rain, however, can damage stone structures and can also be harmful to crops, as well as polluting waterways. It forms in the atmosphere when poisonous gases emitted by human activities combine with the moisture within rain clouds.

Fossil-fuelled power stations and petrol/diesel vehicles give off chemical pollutants – mainly sulphur dioxide (SO_2) and nitrogen oxides (NOx) – which when mixed with the water in the air react and turn acidic.

Acid rain in action



3. Gasses dissolve
Upon combining with the water vapour (water and oxygen) in the rain clouds, the gasses react to form weak but potentially damaging acid. Sulphur dioxide from industry becomes sulphuric acid.

2. Wind
The gases are carried on the wind to higher ground, towards rain clouds.

4. Acid rainfall
When acid rain falls it can damage plant life, infiltrate waterways and erode buildings and statues.

1. Acidic gases
Sulphur dioxide and nitrogen oxides from industry and vehicles are released into the atmosphere.

Oxidation of sulphur and nitrogen

Sulphur dioxide (SO_2)
This is a by-product of heavy industry, such as power stations.

Nitrogen oxides (NOx)
These are released in car exhaust fumes.

KEY:
Blue: Nitrogen
Yellow: Sulphur
Red: Oxygen

© Science Photo Library

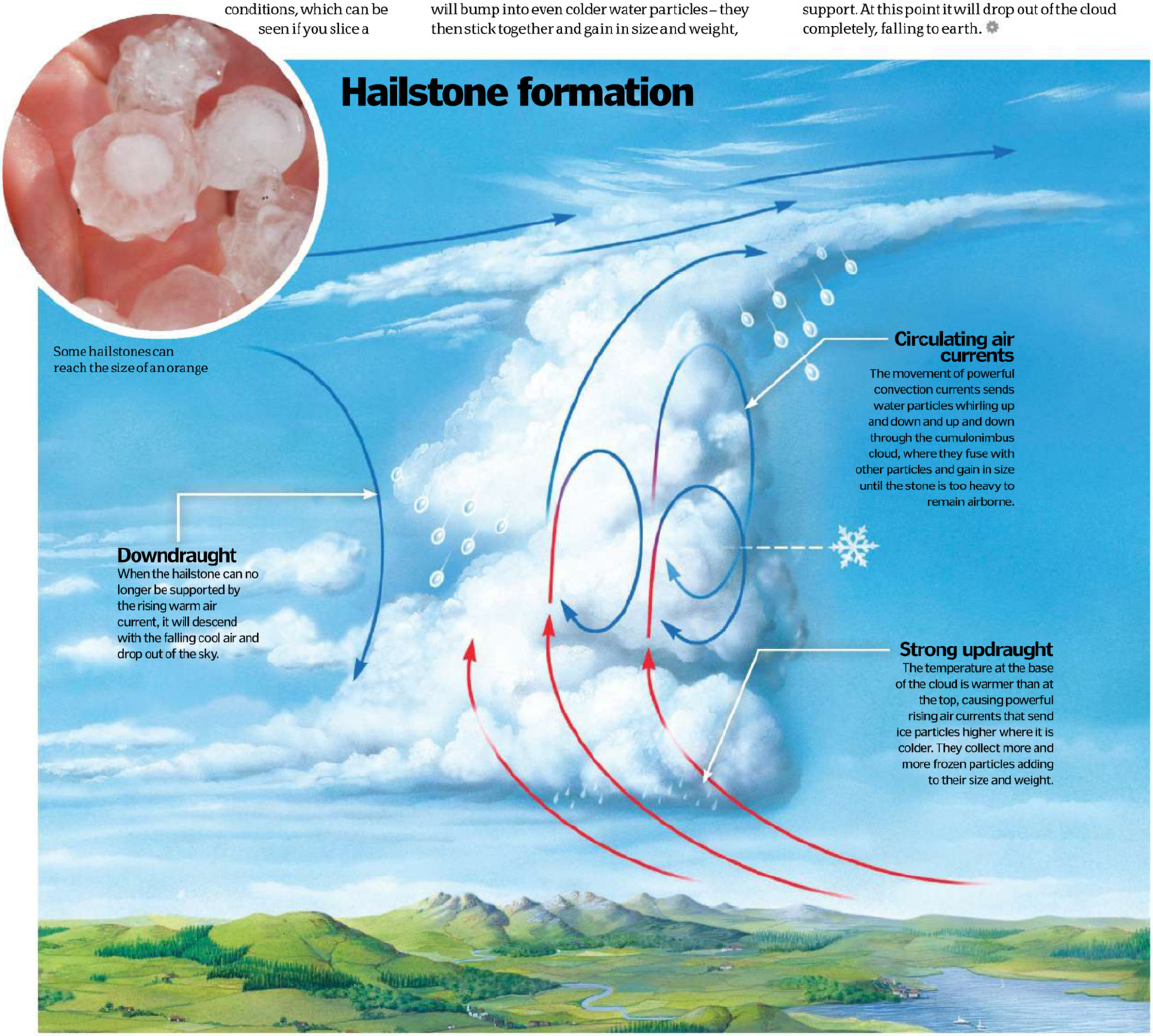
Hailstones

The balls of ice that fall to the ground, ruining crops, denting cars and smashing greenhouses

Hailstones form in the upper parts of freezing storm clouds which feature very powerful convection air currents that stretch up to ten kilometres into the atmosphere. They consist of many layers of either clear, hard ice, or softer milky snow, formed under different conditions, which can be seen if you slice a hailstone in half. Most hailstones are about the size of a marble, but can occasionally be as large as oranges.

Water droplets form inside storm clouds and are drawn upwards by strong rising air currents where they turn into ice. On its journey up, an ice particle will bump into even colder water particles – they then stick together and gain in size and weight, creating another layer of ice. As the hailstone grows heavier, it falls back down through the cloud, colliding with yet more ice particles on their way up.

The hailstone can circulate around the cloud many times, gaining more and more layers of ice, until it becomes too heavy for the air current to support. At this point it will drop out of the cloud completely, falling to earth.



Some hailstones can reach the size of an orange

Hailstone formation

Circulating air currents
The movement of powerful convection currents sends water particles whirling up and down and up and down through the cumulonimbus cloud, where they fuse with other particles and gain in size until the stone is too heavy to remain airborne.

Downdraught
When the hailstone can no longer be supported by the rising warm air current, it will descend with the falling cool air and drop out of the sky.

Strong updraught
The temperature at the base of the cloud is warmer than at the top, causing powerful rising air currents that send ice particles higher where it is colder. They collect more and more frozen particles adding to their size and weight.

The Earth's atmosphere

It's all around us, but how much do we know about our atmosphere?

Our atmosphere (made up of 78 per cent nitrogen and 21 per cent oxygen, with other gases making up the last per cent) is held in place by gravity and consists of a number of different layers that work together to protect us from solar radiation and to keep consistent temperatures. The atmosphere gets thinner with altitude, with 80 per cent of its mass in the first layer closest to the Earth's surface. There are five main layers that make up the atmosphere. The troposphere is the first layer (and is where our weather occurs), followed by the stratosphere, mesosphere, thermosphere and exosphere. There is no definite boundary between where the atmosphere ends and outer space begins, though the Kàrmàn line at 100km above sea level is often regarded as a the boundary.

There are other layers that exist alongside the five main layers. The lowest of these is the 'planetary boundary', which is within the troposphere and closest to the Earth's surface and its depth can vary widely between 100m to 3,000m as it is directly affected by conditions on the surface. The ozone layer is the one that most of us will be familiar with and this is contained within the stratosphere, in its lower portion. Around 90 per cent of the ozone in the atmosphere lies here. The ionosphere is what causes auroras, such as the northern lights, as it is ionised by solar radiation and stretches from 50 to 1,000km, overlapping the exosphere and thermosphere.

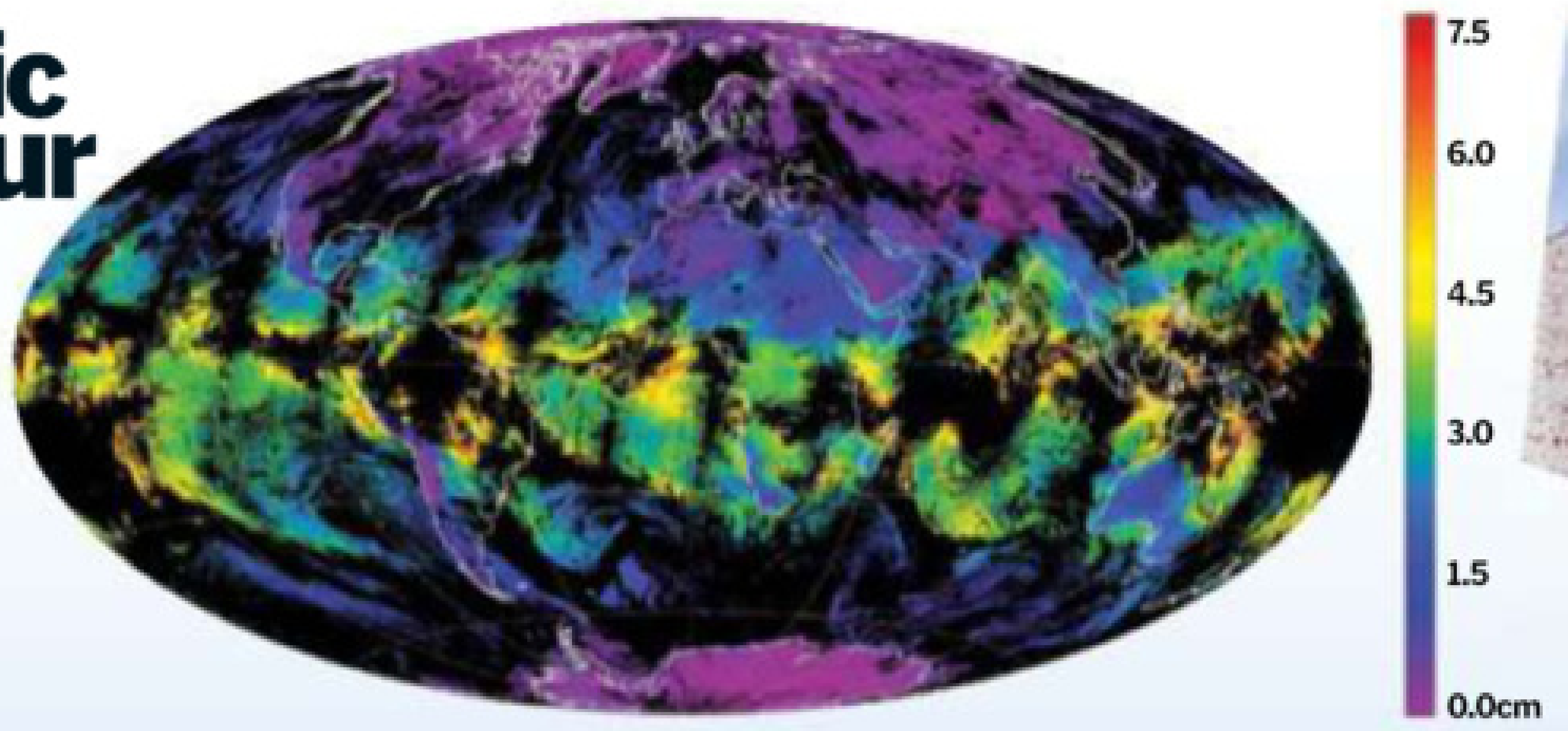
Finally, the homosphere and the heterosphere run from the Earth's surface to around 80km and from 80km upwards respectively. They are so-named because of the way the gases within them are mixed. The heterosphere has a chemical composition that changes with height, whereas the homosphere's make-up remains more constant. The five main layers are based on the thermal structure of the atmosphere, whereas the additional layers mentioned here are classified according to composition.

The northern lights are caused partly by the atmosphere

Atmospheric water vapour

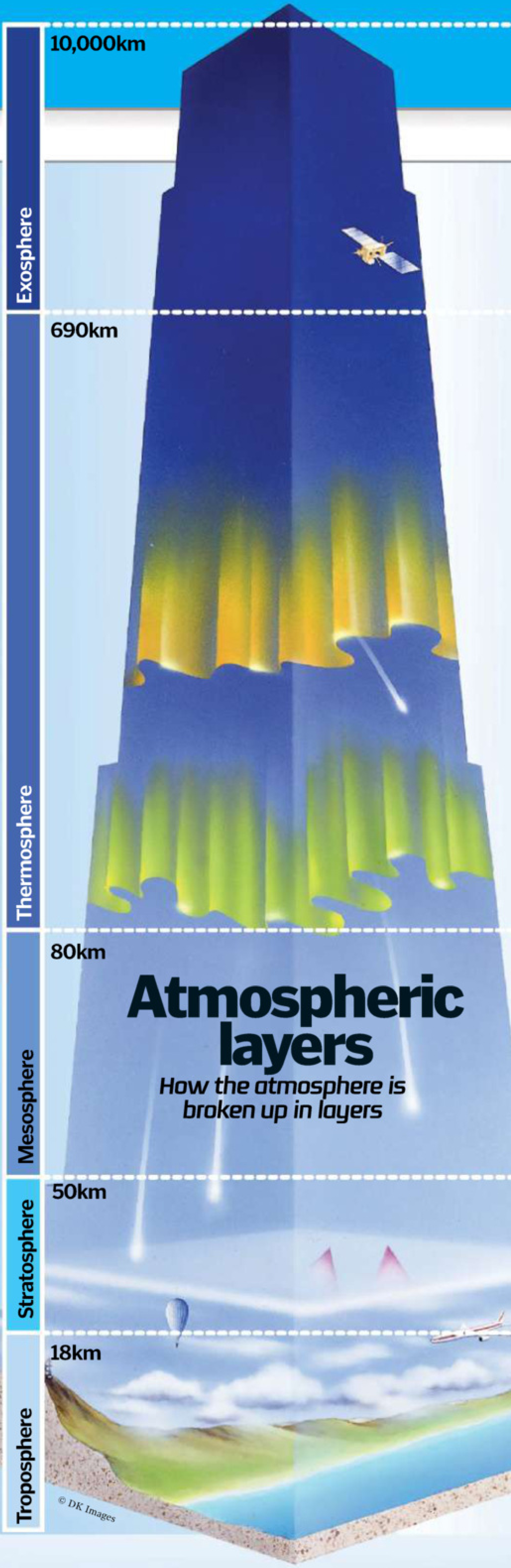
Moisture in the air

The gaseous water vapour in our atmosphere is responsible for our rain, snow, hail, fog, and clouds. If the vapour was to fall evenly over the planet as precipitation, each year 25mm of water will have fallen.



Atmospheric layers

How the atmosphere is broken up in layers



© DK Images

HEAD 2 HEAD OTHER PLANET'S ATMOSPHERES

THIN

1. Mars

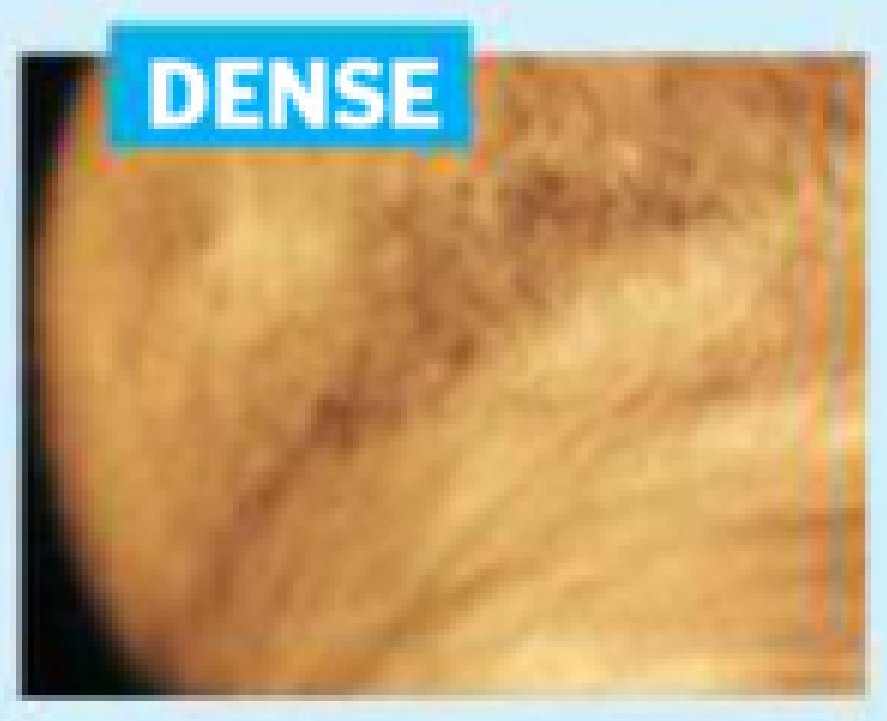
Mars has a thin atmosphere, less than one per cent as dense as that of Earth. CO_2 makes up 95 per cent of the atmosphere and doesn't sufficiently transfer heat.

UNSTABLE

2. Mercury

There are traces of an atmosphere, containing elements including hydrogen, helium, oxygen and sodium, but it's difficult to calculate its pressure.

DENSE



3. Venus

Venus has a hot, dense atmosphere, which leads to an absence of liquid water. It has a high percentage of CO_2 and a mean temperature of 460˚C.

DID YOU KNOW? *The atmosphere reaches out to a whopping 10,000km above the Earth's surface*

5. Exosphere

The final layer where particles are widely spaced and can travel hundreds of kilometres before colliding with another particle. The makeup of this layer is mainly hydrogen and helium.

© NASA

4. Thermosphere

Temperatures start to increase with height. This is also the layer in which the International Space Station orbits, between 320 and 380km, and shuttles fly into. It extends up to the base of the exosphere, called the exobase.

This rock made it through the mesosphere

3. Mesosphere

Extends from the stratopause (again, the layer boundary) to a height of 80-85km and is notably the layer in which meteors burn up when entering the atmosphere. Temperatures decrease with height, and in the mesopause is the coldest place on Earth (around -100°C).

2. Stratosphere

Starts from the tropopause (the boundary between the first two layers) up to around 51km, with temperatures increasing with height. This is where you'll find things like weather balloons.

1. Troposphere

The first layer of atmosphere, starting at the Earth's surface and extending to between 7km and 17km. It is heated by a transfer of energy from the Earth's surface, so it gets cooler as it goes higher.

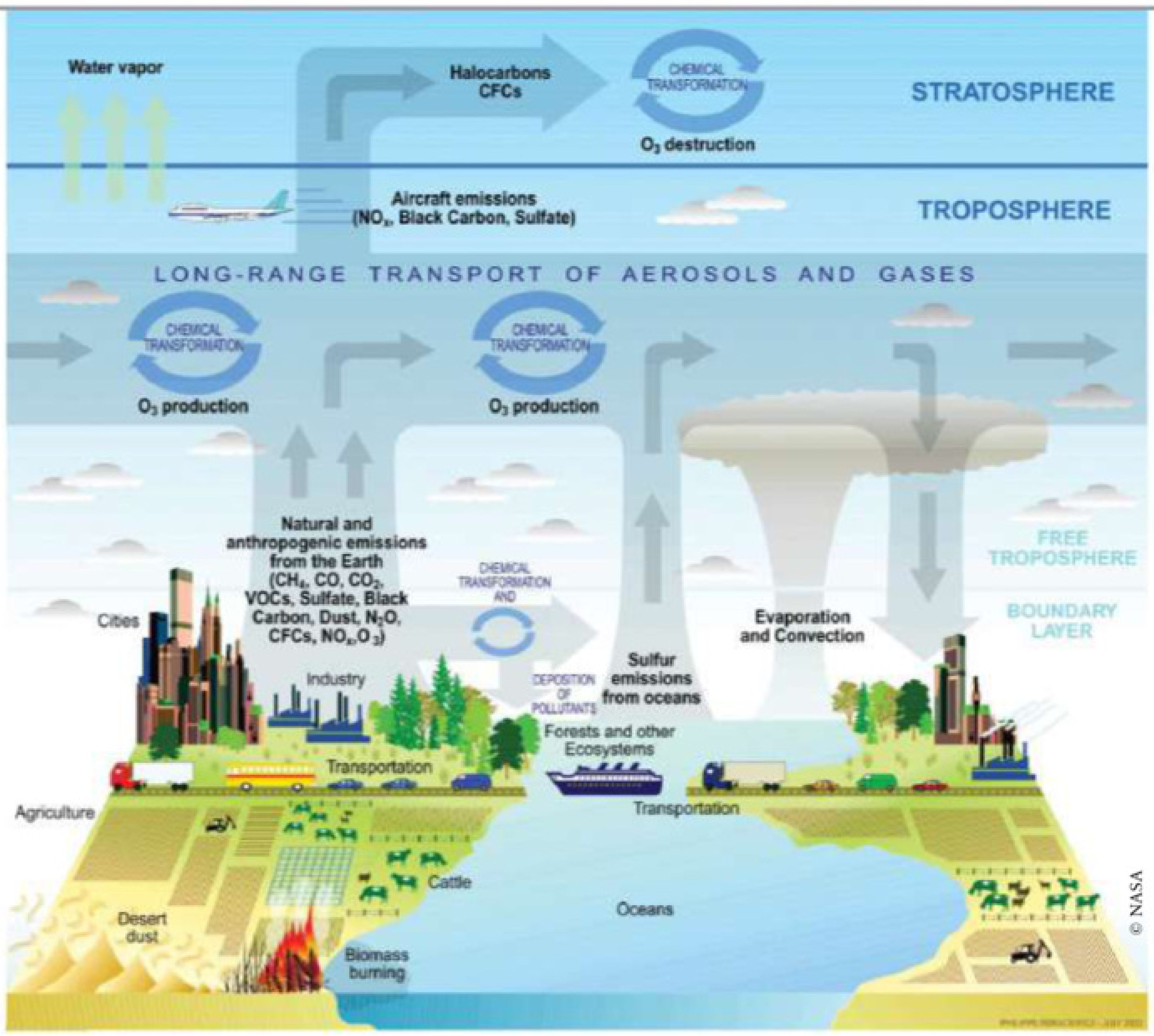
Pollution in the air

The effects of pollution include smog, acid rain, the greenhouse effect, and holes in the ozone layer. Each problem has implications for both our health and the environment.

The carbon dioxide gas produced when fuel is burned may contribute to the greenhouse effect. Plants can convert CO_2 back to oxygen, but the human production of Co$_2$ currently exceeds the amount the plants can convert back.

Rife in cities, smog is the result of smoke, fog, and chemical fumes caused when different pollutants combine.

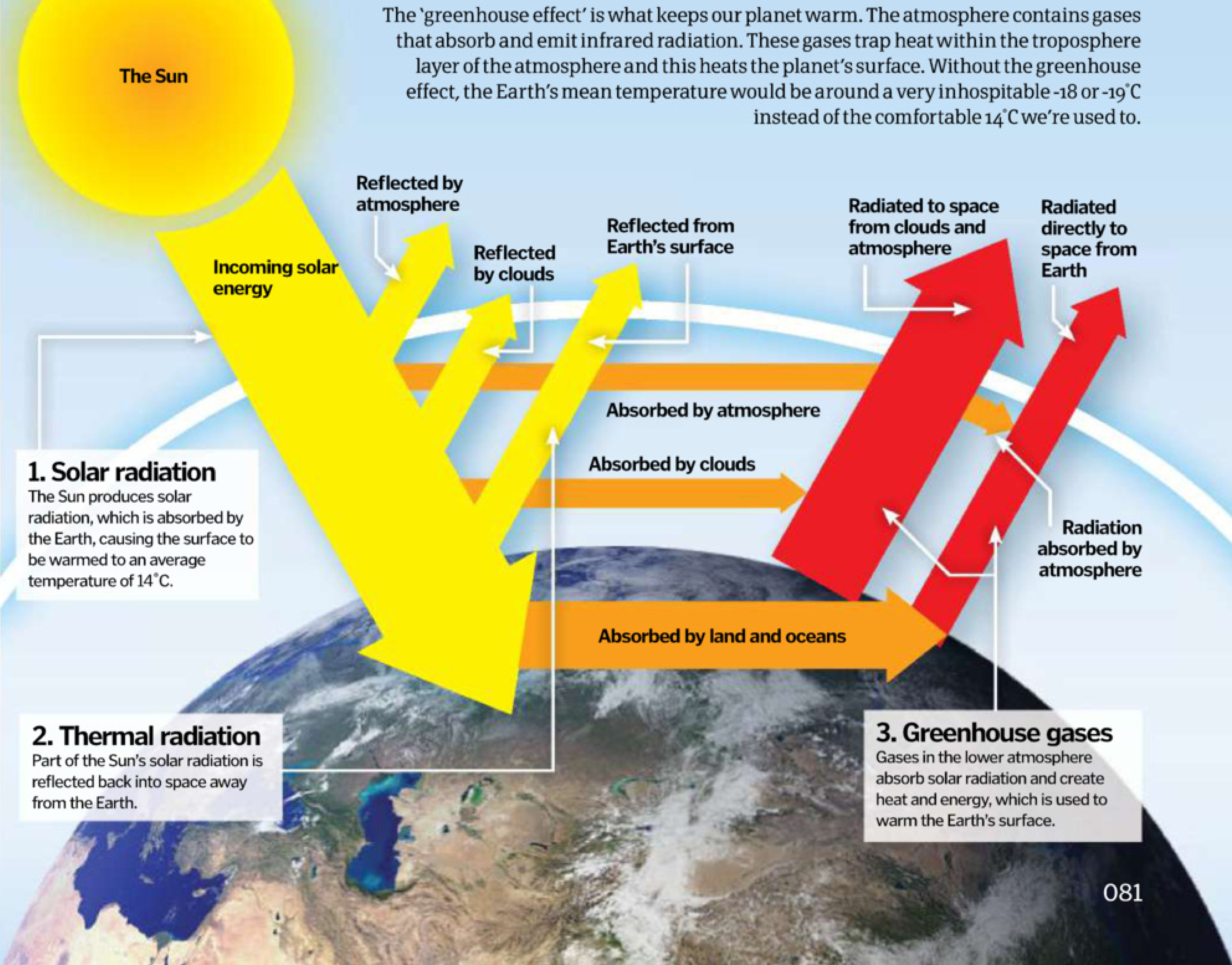
Acid rain occurs when a pollutant, such as sulfuric acid combines with droplets of water in the precipitation and becomes acidified.


Water vapor
Halocarbons CFCs
CHEMICAL TRANSFORMATION
O₃ destruction
STRATOSPHERE
Aircraft emissions (NOₓ, Black Carbon, Sulfate)
TROPOSPHERE
LONG-RANGE TRANSPORT OF AEROSOLS AND GASES
CHEMICAL TRANSFORMATION
O₃ production
CHEMICAL TRANSFORMATION
O₃ production
Natural and anthropogenic emissions from the Earth (CH₄, CO, CO₂, VOCs, Sulfate, Black Carbon, Dust, N₂O, CFCs, NOₓ, O₃)
CHEMICAL TRANSFORMATION AND
DEPOSITION OF POLLUTANTS
Sulfur emissions from oceans
Evaporation and Convection
FREE TROPOSPHERE
BOUNDARY LAYER
Cities
Industry
Forests and other Ecosystems
Transportation
Transportation
Agriculture
Cattle
Oceans
Desert dust
Biomass burning

© NASA

The greenhouse effect

The 'greenhouse effect' is what keeps our planet warm. The atmosphere contains gases that absorb and emit infrared radiation. These gases trap heat within the troposphere layer of the atmosphere and this heats the planet's surface. Without the greenhouse effect, the Earth's mean temperature would be around a very inhospitable -18 or -19˚C instead of the comfortable 14˚C we're used to.


The Sun
Incoming solar energy
Reflected by atmosphere
Reflected by clouds
Reflected from Earth's surface
Radiated to space from clouds and atmosphere
Radiated directly to space from Earth
Absorbed by atmosphere
Absorbed by clouds
Radiation absorbed by atmosphere
Absorbed by land and oceans

1. Solar radiation

The Sun produces solar radiation, which is absorbed by the Earth, causing the surface to be warmed to an average temperature of 14˚C.

2. Thermal radiation

Part of the Sun's solar radiation is reflected back into space away from the Earth.

3. Greenhouse gases

Gases in the lower atmosphere absorb solar radiation and create heat and energy, which is used to warm the Earth's surface.

HOW IT WORKS

SPACE WEATHER

Discover the weather from outer space

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Discover the story behind twisters on the Sun

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Learn all about the mega-waves of energy

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Where does Venus' high temperature come from?

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How does space have weather with no atmosphere?

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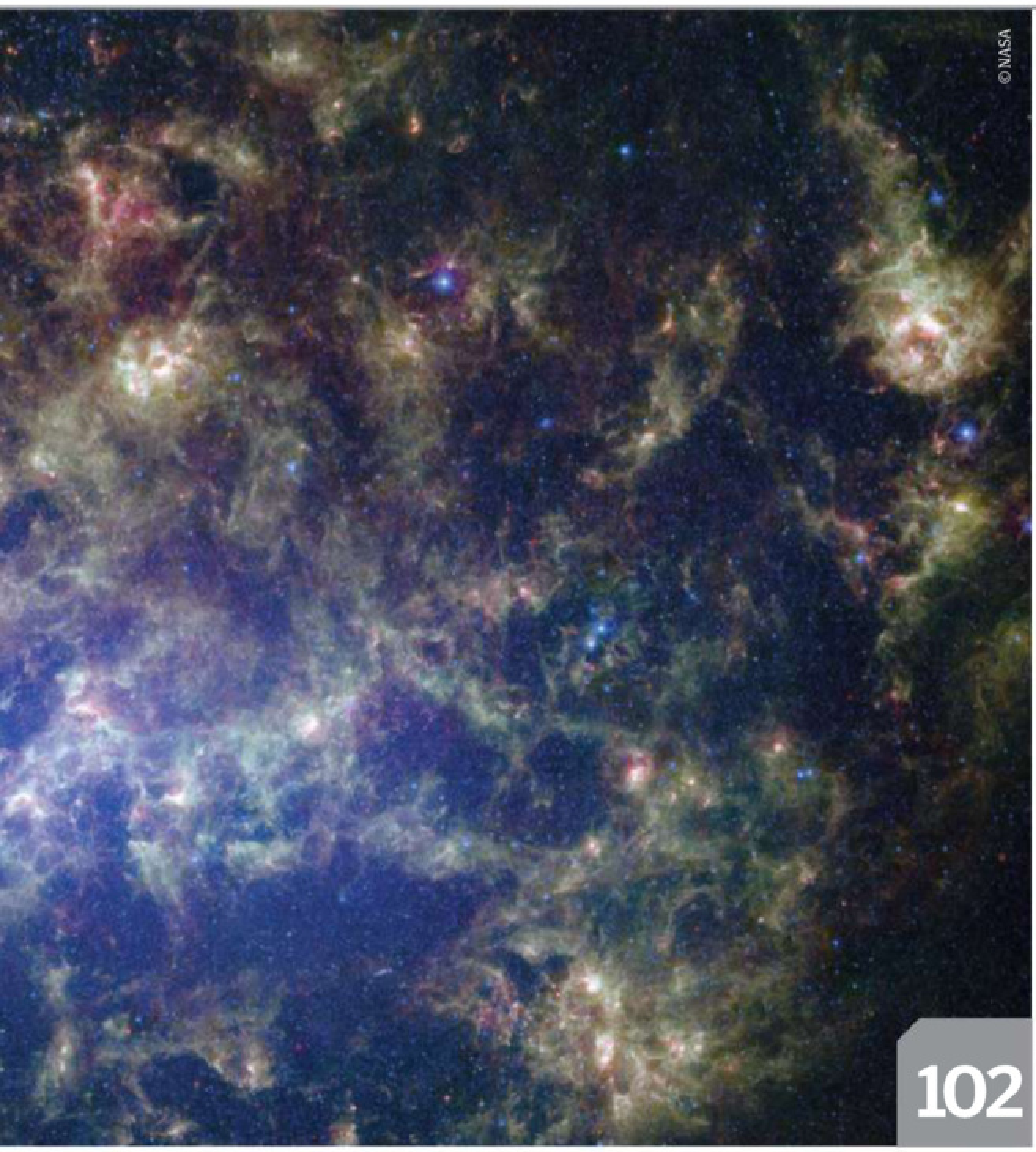
How was this stunning image captured?

104 Wildest weather in space
Learn about space's wildest weather systems



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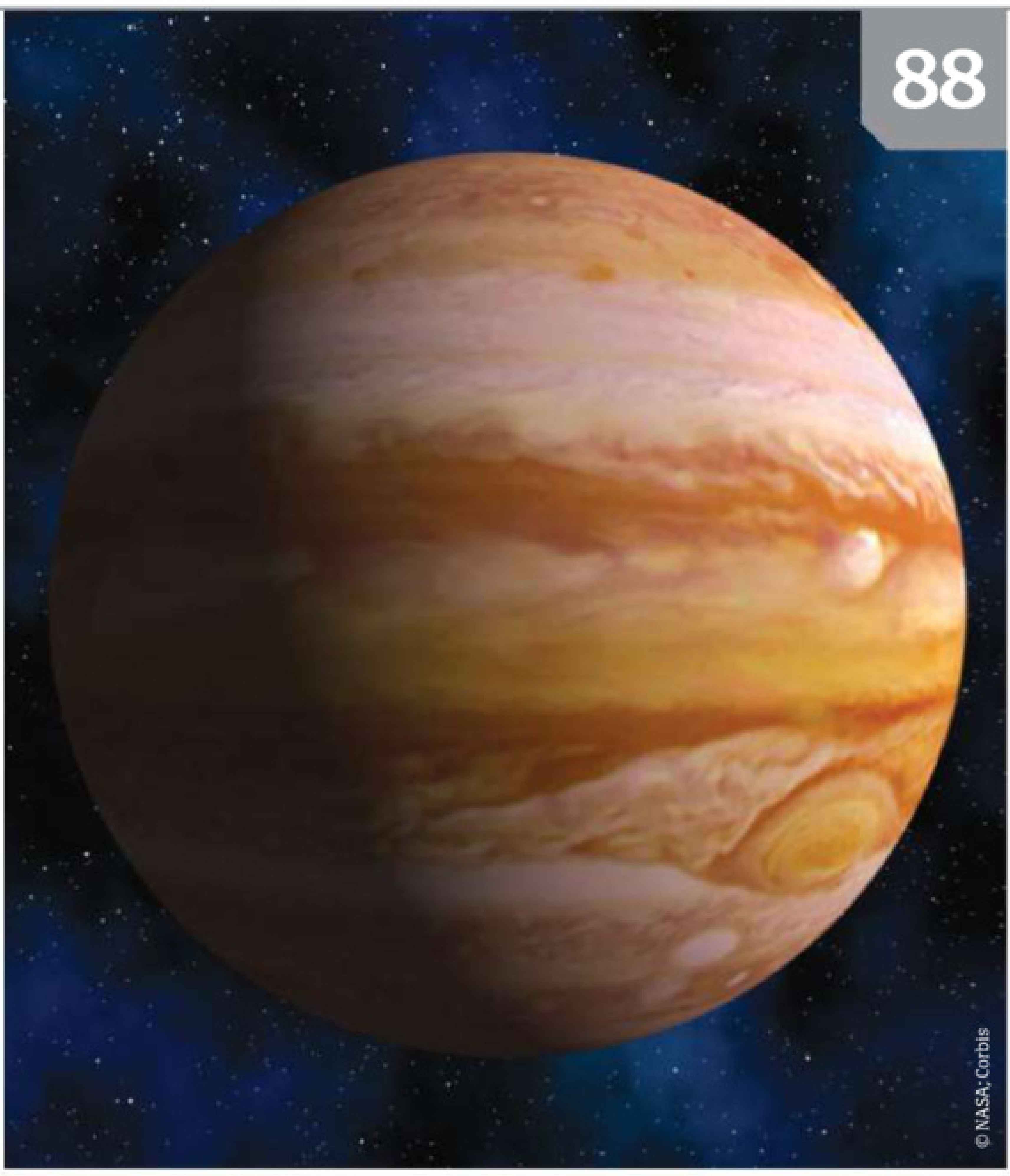

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Deadly solar storms

Discover why huge explosions from the Sun can cause major problems on Earth

Weather isn't just a phenomenon for Earth's atmosphere; there's an entirely different type of weather occurring out in the space between Earth and the Sun, thanks to changes in the latter's magnetic activity cycle. Among other things, this cycle modulates powerful outbursts from the Sun's surface that can have a direct impact on our lives. These are known as geomagnetic, or solar, storms.

Solar storms can also include a wide range of related phenomena, including auroras and electromagnetic emissions as well as solar energetic particle events, solar flares, and coronal mass ejections. Some of these have little effect on Earth.

5 TOP FACTS
WEIRD SOLAR ACTIVITY

Black hole sun

1 The Sun gets holes in its corona. These areas are darker and colder than the surrounding area and have open magnetic field lines, allowing for solar wind to develop.

Solar tsunamis

2 Solar flares generate massive, fast-moving shock waves on the corona known as Moreton waves. They can move as fast as 1,500 kilometres (932 miles) per second.

Loop the loop

3 Cooled plasma can loop 700,000km (435,000 mi) from the Sun's surface in a formation known as a solar prominence. They can break off and form coronal mass ejections.

Parker spiral

4 Thanks to the influence of solar wind, the Sun's magnetic field takes on the shape of an arithmetic spiral as it rotates and extends throughout the solar system.

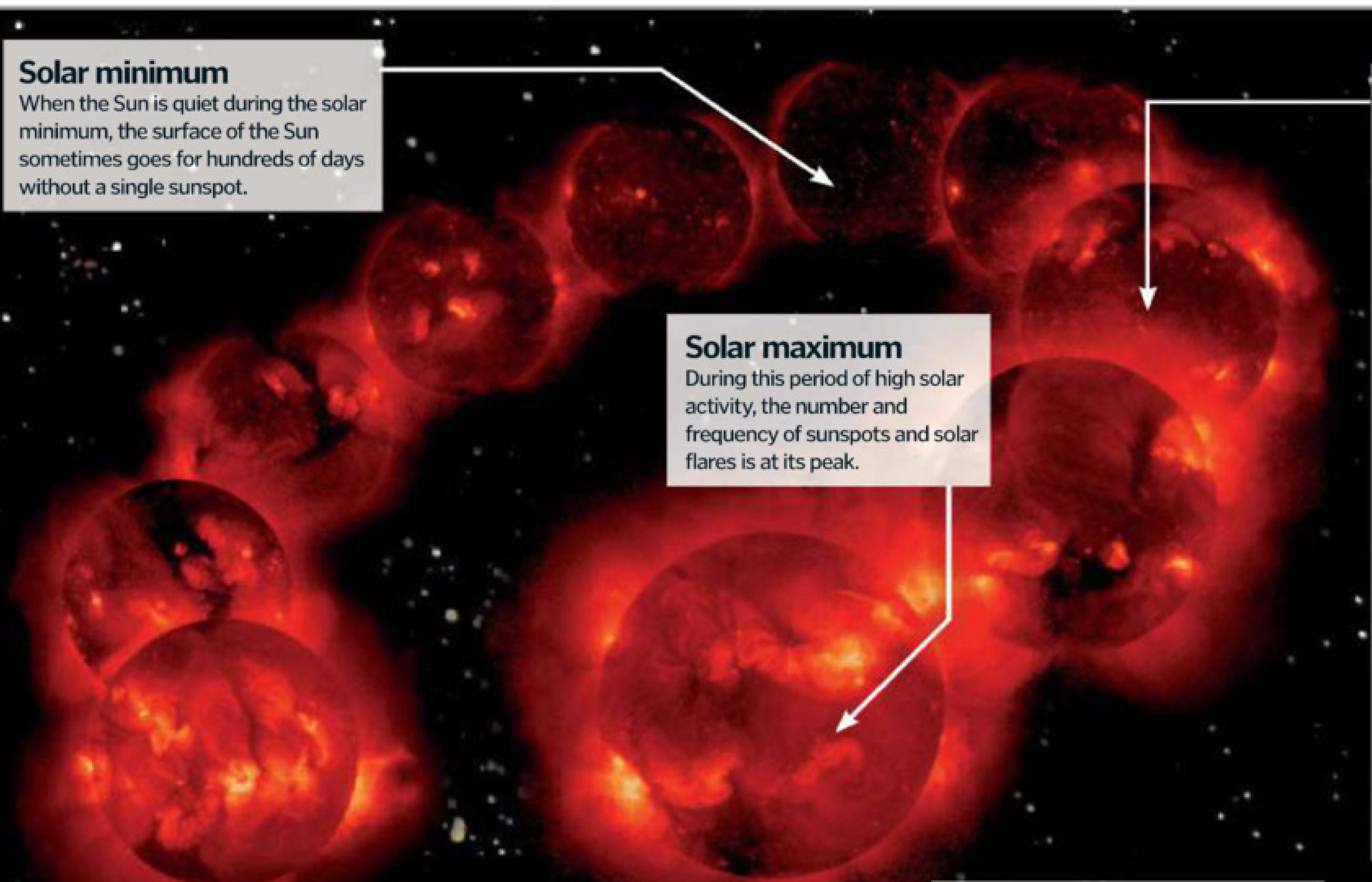
Somersaulting Sun

5 During the solar maximum, the Sun's poles switch – the north pole points south and vice versa – as increased sunspot activity causes its magnetic field to change.

DID YOU KNOW? *Some estimate that a super solar storm could cause $2 trillion USD in damage*

The solar cycle

Sunspots are temporary dark spots of intense magnetic activity on the Sun's surface. They change according to a cycle that lasts roughly 11 years. Clustered into two bands around the Sun's mid-latitudes, they move closer to the equator over the course of the cycle. During the cycle, the period of fewest sunspots is the solar minimum, while the time of greatest activity is the solar maximum. This cycle has been a quiet one, with 50 per cent less activity than predicted. However, astronomers believe we are now approaching solar maximum, with the apex occurring in 2013, and wonder if the Sun might make up for lost time with more intense solar storms.

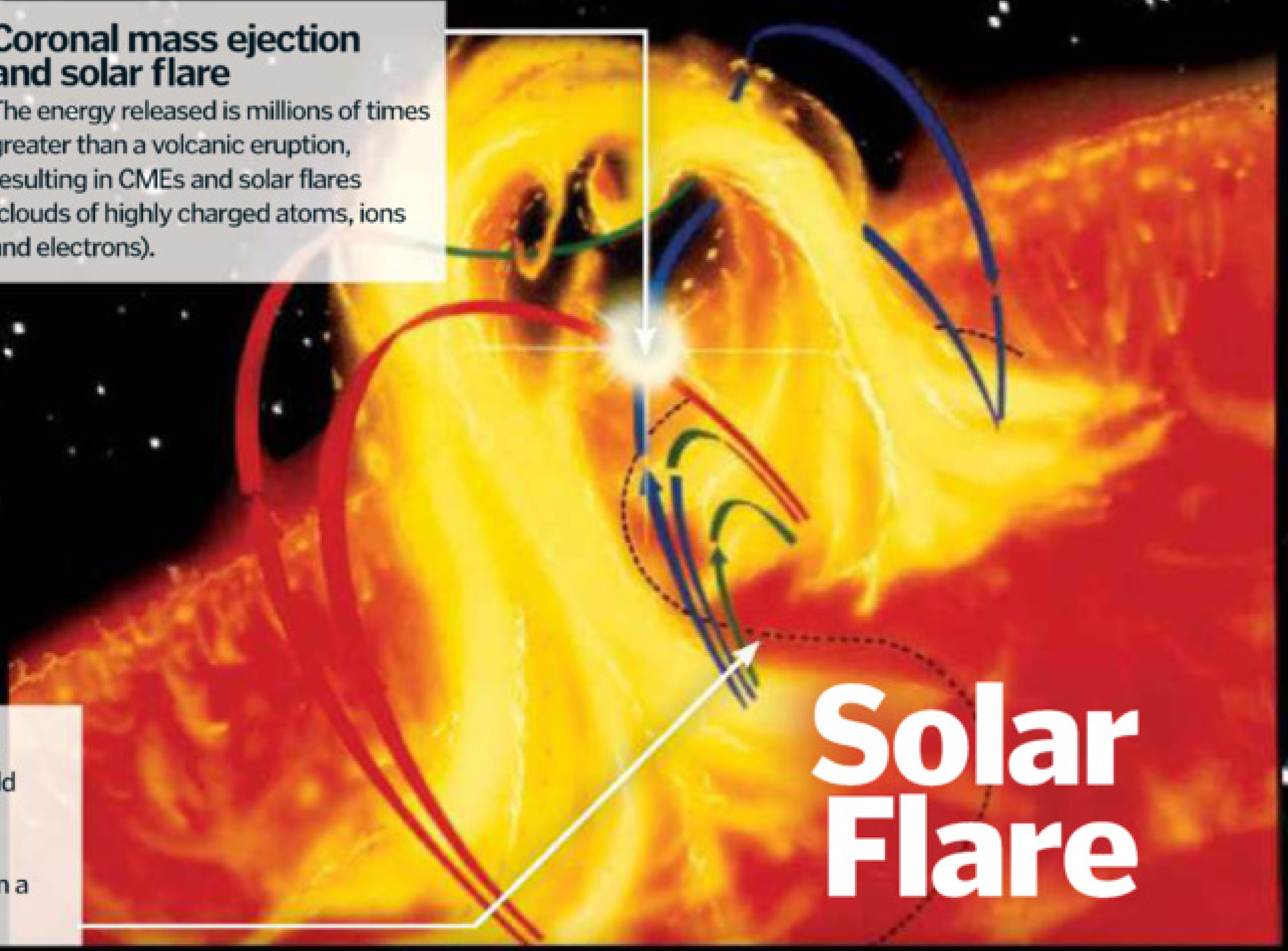


Solar minimum
When the Sun is quiet during the solar minimum, the surface of the Sun sometimes goes for hundreds of days without a single sunspot.

Solar maximum
During this period of high solar activity, the number and frequency of sunspots and solar flares is at its peak.

All Images © NASA

Solar Flare



Coronal mass ejection and solar flare
The energy released is millions of times greater than a volcanic eruption, resulting in CMEs and solar flares (clouds of highly charged atoms, ions and electrons).

Magnetic field lines
North and south magnetic field lines break through the Sun's surface near sunspots and reconnect in loops, resulting in a massive burst of energy.

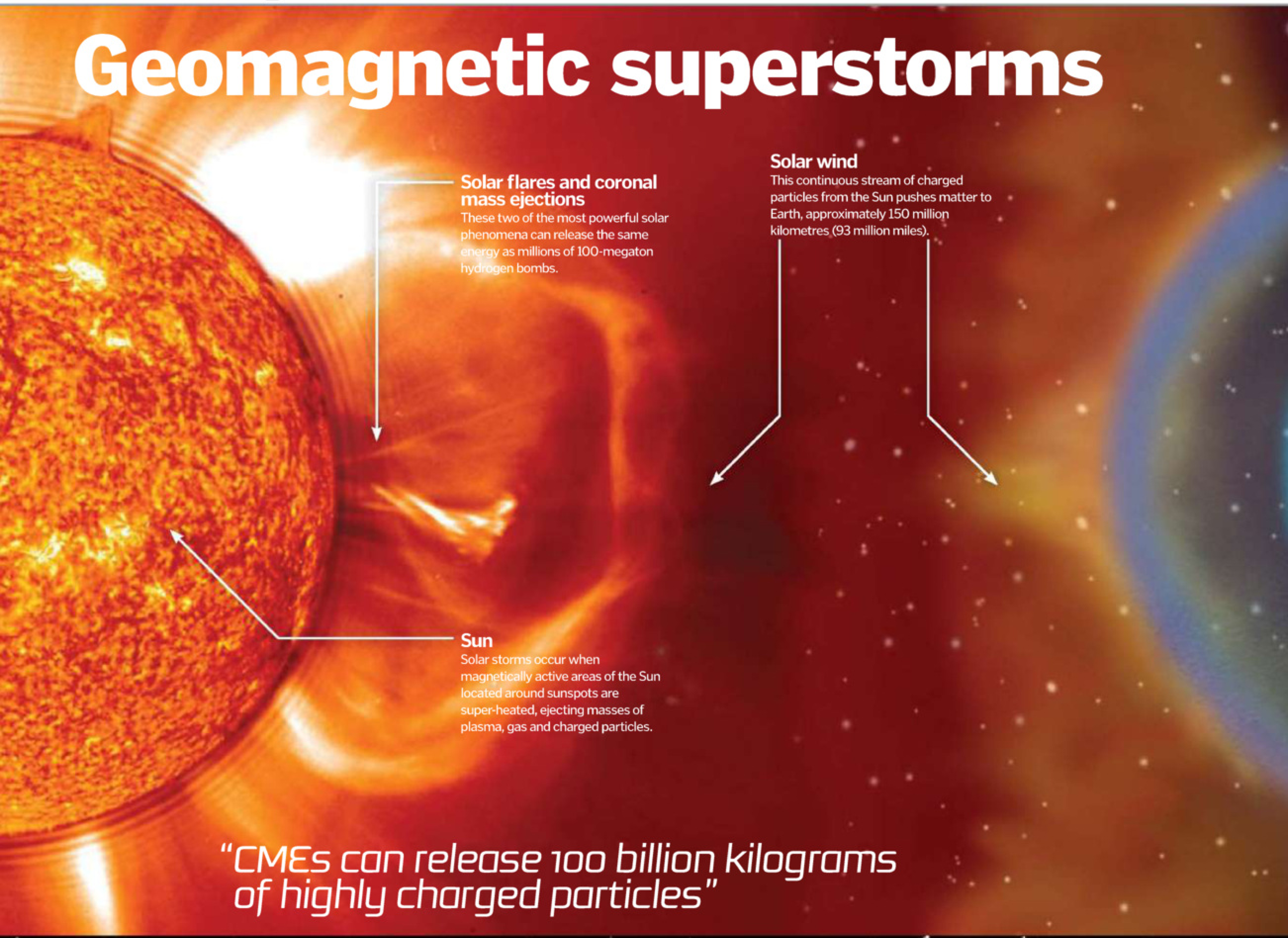
Not all solar storms affect Earth

For example, charged particles driven into the Earth's upper atmosphere by solar wind impact with atoms and create the beautiful, luminous glow known as the auroras in the high-latitude areas of the Northern and Southern Hemisphere. However, not all space weather phenomena is innocuous – some can even be fatal. A solar proton event (SPE) has the ability to endanger the life of astronauts. SPEs are a type of cosmic ray that occurs in conjunction with other solar storm phenomena such as solar flares. Comprising electrons, protons, and heavy ions that are extremely high-energy, some SPEs can be as fast as 80 per cent the speed of light. The resulting radiation can damage DNA and increase astronauts' risk of cancer and other diseases. At high, prolonged doses, exposure can lead to death. In addition, the sensitive instruments on spacecraft can be affected, causing problems with navigation or power. Very high-energy solar proton events can theoretically even harm passengers on high-altitude aircraft flights.

But what happens when an event has a direct impact on us here on Earth? A coronal mass ejection (CME) occurs when the Sun releases a huge burst of charged particles known as solar wind, along with plasma and radiation, from a cluster of sunspots. Depending on the velocity at which it was released, a CME can reach the Earth's magnetosphere, or magnetic field. The highly charged particles of solar wind can be powerful enough to cause a shock wave and disturb the magnetosphere. The resulting release of plasma and radiation, while not biologically dangerous (our atmosphere absorbs the most harmful radiation), can disrupt everything from power grids and oil drilling on the ground to communications and GPS satellites in the atmosphere.

In 1859, the largest solar storm ever recorded hit Earth. Named the Carrington Event in honour of the astronomer who first viewed it, this storm started with a solar flare. This led to a CME that travelled to Earth in 18 hours (as opposed to the three or four days that they typically take). Because we're so reliant upon high-tech electronic systems, powerful solar storms like the Carrington Event have the potential to cause serious damage. Subsequent storms have had serious effects. In 1960 there was another solar storm that caused widespread radio blackouts. A more intense storm in 1989 left 6 million people in the dark in Quebec when a power grid failed – but we have yet to experience another superstorm like that in 1859. ✻

Geomagnetic superstorms



Solar flares and coronal mass ejections
These two of the most powerful solar phenomena can release the same energy as millions of 100-megaton hydrogen bombs.

Solar wind
This continuous stream of charged particles from the Sun pushes matter to Earth, approximately 150 million kilometres (93 million miles).

Sun
Solar storms occur when magnetically active areas of the Sun located around sunspots are super-heated, ejecting masses of plasma, gas and charged particles.

> *"CMEs can release 100 billion kilograms of highly charged particles"*

Super-strong storms

Solar storms and the resulting phenomena can be amazingly powerful, especially solar flares and coronal mass ejections. Solar flares and CMEs can release the same amount of energy as millions of 100-megaton hydrogen bombs exploding at once. The largest ones emit up to 1032 ergs, which is 10 million times the energy released during an average volcanic explosion on Earth. CMEs can also release 100 billion kilograms (220 billion pounds) of highly charged particles at a speed of 1,000 kilometres (621 miles) per second.

The largest solar storms emit 10 million times more energy than a volcanic explosion

© OliverSpalt

HEAD2HEAD
EXTREME SUN EFFECTS

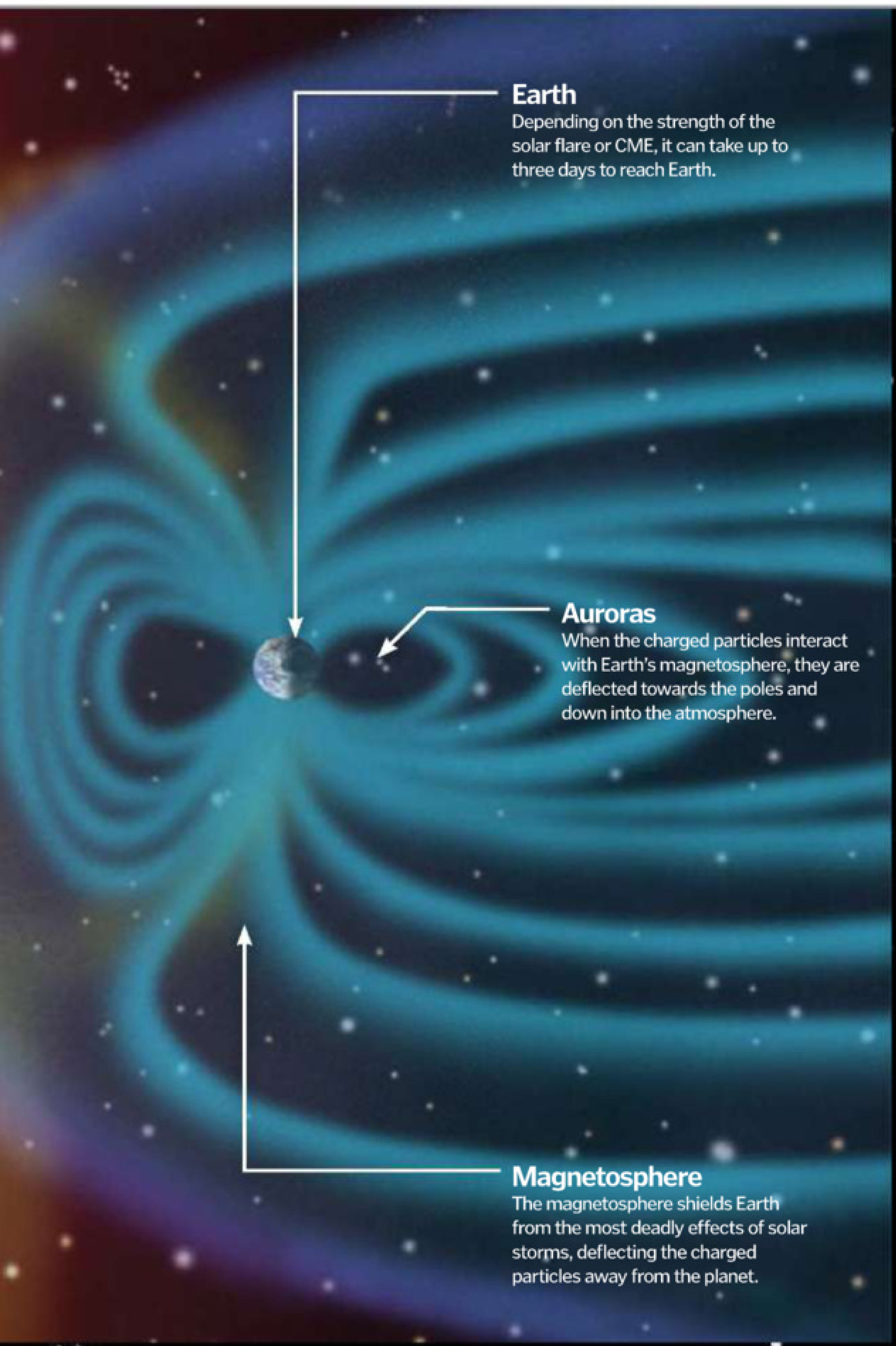
1. Ultraviolet radiation
Exposure to UV rays can cause skin cancer, including melanoma, which accounts for 75 per cent of skin cancer deaths.

© Jen, 2009

2. Electromagnetic radiation
The loss of power and communications from a severe solar storm has the potential to cause numerous deaths around the world.

3. X-Class solar flare
An astronaut standing on the moon during these strongest of solar flares could die instantly from radiation poisoning.

DID YOU KNOW? *During the Carrington Event, some telegraph operators could still send messages due to the storm's currents*



Earth
Depending on the strength of the solar flare or CME, it can take up to three days to reach Earth.

Auroras
When the charged particles interact with Earth's magnetosphere, they are deflected towards the poles and down into the atmosphere.

Magnetosphere
The magnetosphere shields Earth from the most deadly effects of solar storms, deflecting the charged particles away from the planet.

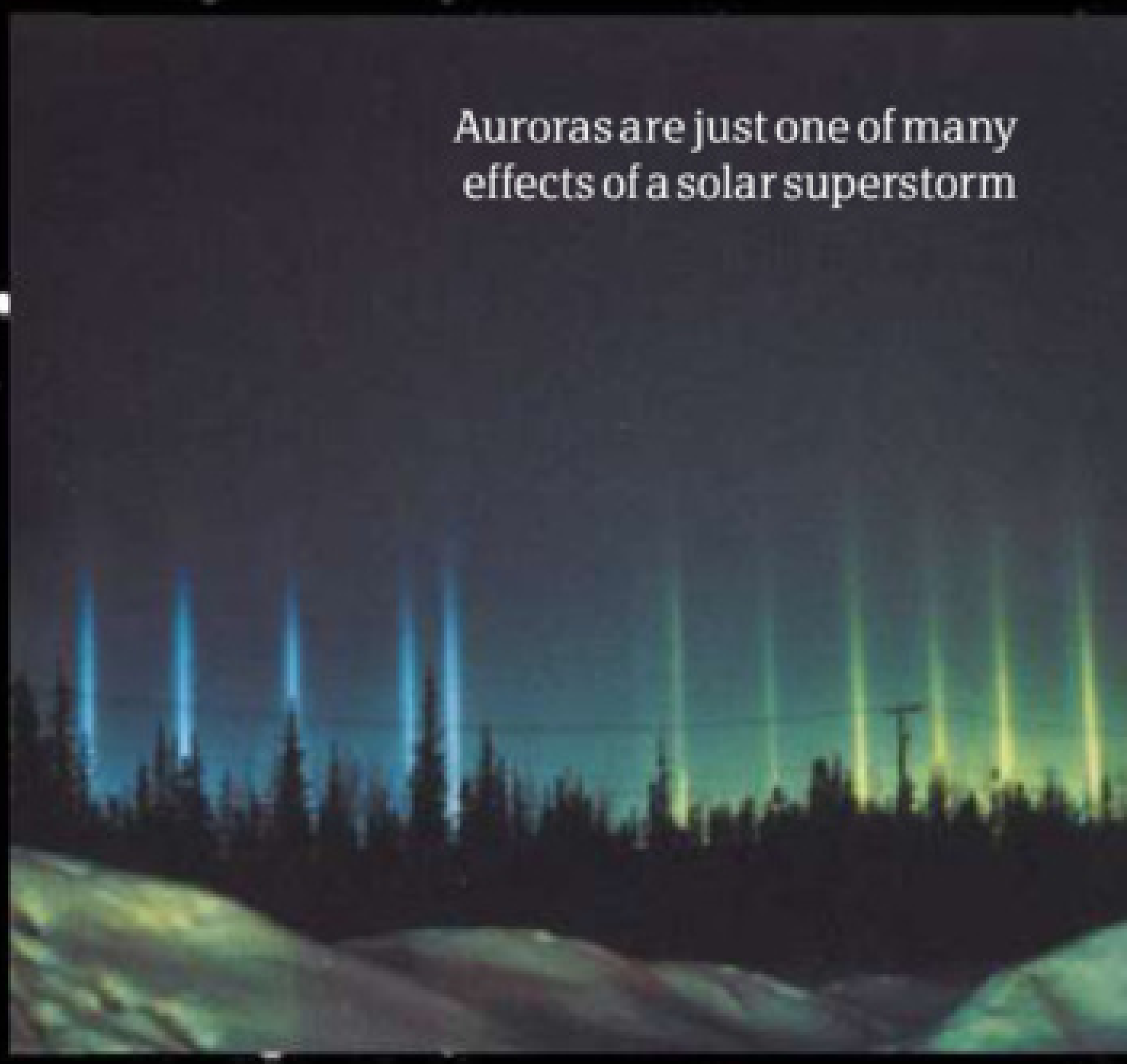
Super solar storm effects

The Carrington Event, the most severe solar storm ever recorded, wreaked havoc from 28 August to 2 September 1859. Telegraph systems in North America and Europe were disrupted by the powerful electrical currents. They electrocuted telegraph operators, while snapped wires sent out sparks and set fires. Intense red and green auroras were reported in places they'd never been seen before, including the Rocky Mountains and the Caribbean.

A storm like the Carrington Event would have a much greater effect on our society. Radios, for example, rely on reflections of waves off the ionised gas in the Earth's ionosphere. Intense radiation disrupts the gas and prevents reflection, rendering radios useless. Air heated by intense ultraviolet emissions would rise and increase the density of the gasses in low-Earth orbit, putting drag on satellites stationed there and causing them to slow down or even fall out of orbit entirely. The flood of charged ions and electrons would also cause electronic overloads, either damaging or disabling the satellites entirely. Electronic currents entering power lines could overload transformers and generators and blow them out. Travel would come to a standstill as planes would be unable to navigate and power grid failures could leave people in the dark for weeks or even months.

The main effects of a solar superstorm

- Auroras
- Radio and TV blackouts
- Mobile phone tower failures
- Astronauts and satellites at risk
- Power grid failure
- Networks offline
- Phantom currents in power lines
- Hardware damaged
- Air travel crippled
- Banking systems down
- Exploding gas lines

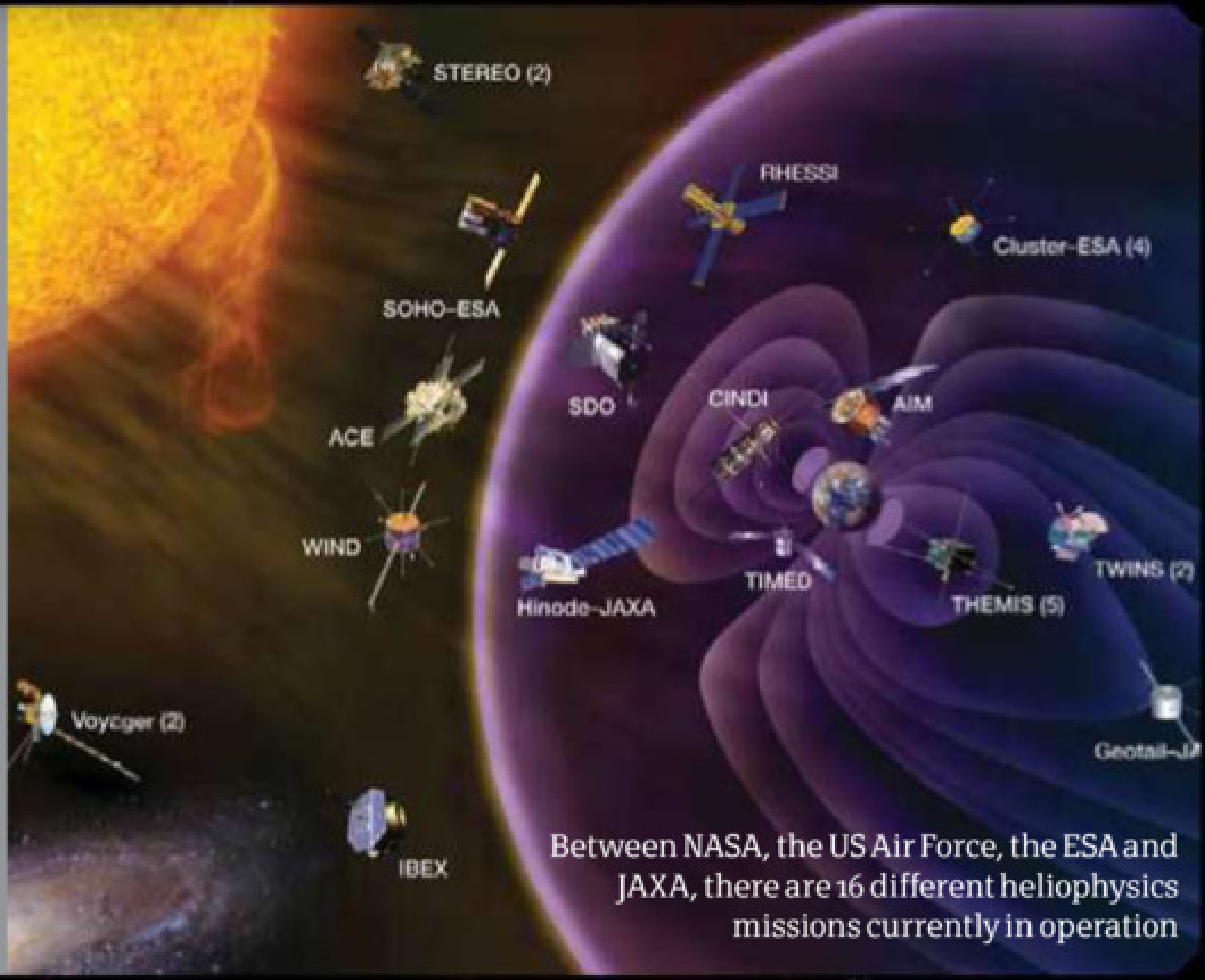


Auroras are just one of many effects of a solar superstorm

Space weather forecasts

NASA has several different spacecraft and satellites in place to report on space weather. These include two spacecraft orbiting on opposite sides of the Sun, known as STEREO (Solar Terrestrial Relations Observatory), that can provide stereoscopic images of 90 per cent of Sun's surface to catch the first signs of activity such as CMEs and solar flares.

The Solar Dynamics Observatory (SDO), gives readings of the Sun's magnetic activity, UV output and images from near Earth. Finally, the satellite known as ACE monitors solar wind and radiation, with the ability to give a 30-minute warning before a storm hits the Earth. Accurate space weather forecasts can give us the time to do things like divert planes, put satellites and communications hubs into 'safe' mode, and even identify and disable power transformers that are most at risk.



Between NASA, the US Air Force, the ESA and JAXA, there are 16 different heliophysics missions currently in operation

Amazing Martian weather

From dust devils to carbon dioxide ice fans, Mars sees some weird phenomena

Martian dust devils are one example of the unusual weather found on the Red Planet. A dust devil is a 'skinny' whirlwind that on Earth forms when hot air near the surface rises rapidly through a pocket of cooler, lower-pressure air and begins to rotate. This creates a spinning column of air – typically 10-50 metres (33-164 feet) in height – that has enough energy to suck up surface dust.

Martian dust devils are in a different league to those on Earth. Typically 50 times as wide and often several kilometres high – as well as boasting intense rotational energy that can suck up vast quantities of dust and rocks – dust devils on Mars are more akin to super-tornadoes. Indeed, they are so powerful that they leave a visible trail of chaos in their wake, in the form of huge snake-like streaks.

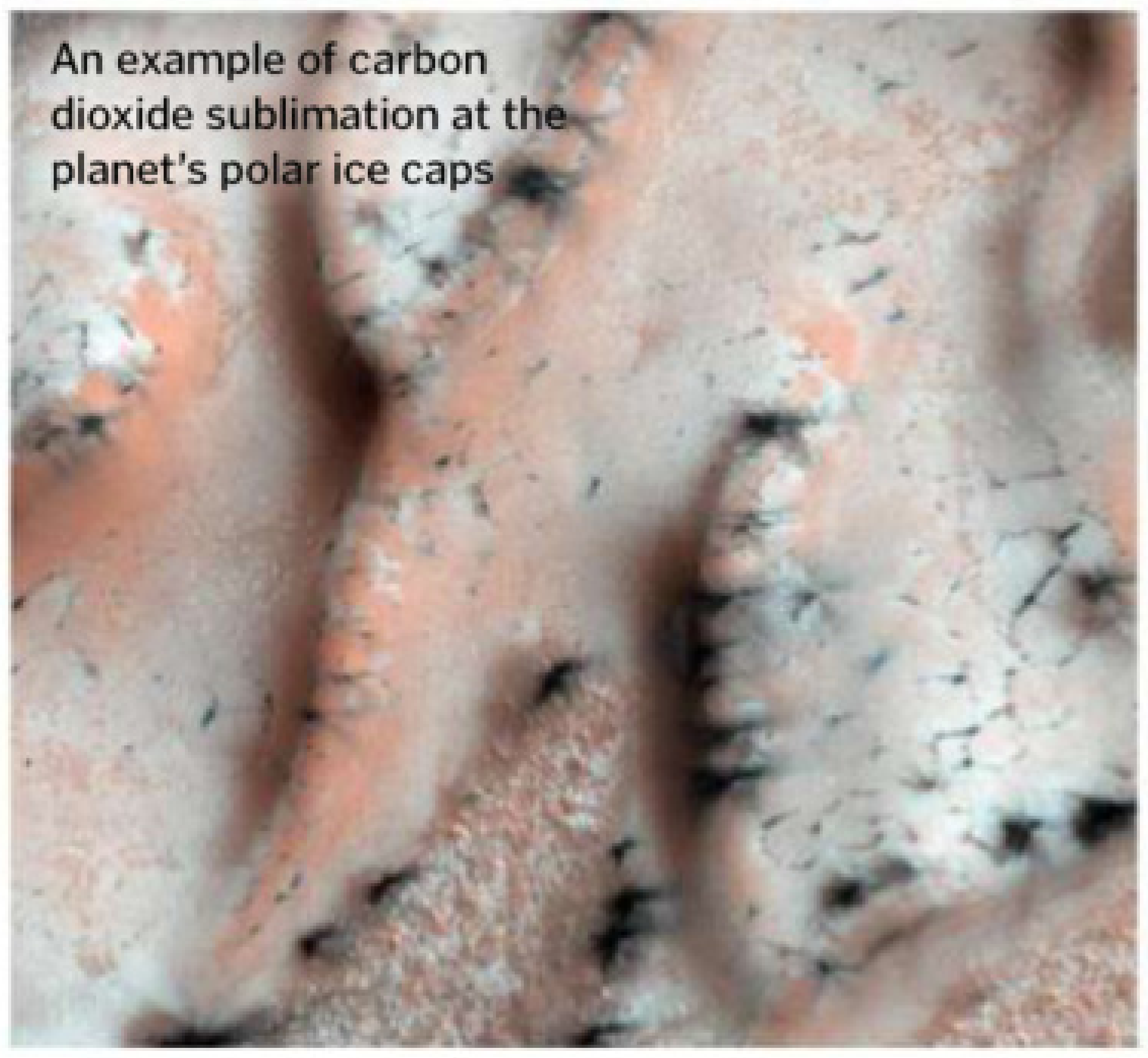
Talking of dust, the dust storms on Mars have the ability to shroud the entire planet in a violent gauze of particulate matter moving at 145 kilometres (90 miles) per hour-plus that can reduce visibility to less than five per cent of that under normal conditions.

These epic storms form in the planet's southern hemisphere during the spring and summer seasons. Activity is first heavily localised, however when the amount of carried dust reaches a critical quantity, the storm rapidly intensifies and spreads, carried to the far-flung reaches of the Red Planet through strong jet streams at speeds commonly in excess of 100 metres (328 feet) per second.

Another prominent feature on Mars that is driven by its seasons is the sublimation (rapid vaporisation) of carbon dioxide ice near the planet's surface. This occurs when Mars's seasonal winter caps of frozen carbon dioxide are quickly heated and transformed into vapour in spring. The gaseous CO_2 then escapes through gaps in the ice, carrying dust with it, and is spread by local winds over the surface, often into distinctive fan shapes.

Mars also has clouds like Earth. These clouds, however, generally form much higher in the atmosphere than ours (ie 80-100 kilometres/50-62 miles up) and are made of carbon dioxide. They are also very faint, resembling mesopheric clouds, and can only form around minuscule grains blown high into the atmosphere during dust storms.

Rock fragments and dust are collected from Mars's surface and transported to its farthest reaches by powerful jet streams



An example of carbon dioxide sublimation at the planet's polar ice caps

Martian dust devils cruise across the planet's surface, leaving a serpentine tail of dust and rock in their wake

© NASA

THE STATS
JUPITER

140,000km AVERAGE DIAMETER

16,500km GREAT RED SPOT SIZE

10 HOURS IN A DAY

-145°C LOWEST TEMPERATURE

AVERAGE WIND SPEED **360km/h**

HIGHEST TEMPERATURE **35,500°C**

DID YOU KNOW? *17th-century astronomer Giovanni Cassini called the Great Red Spot the "Eye of Jupiter"*

Weather on Jupiter

The forecast is raging storms and swirling winds

If you've ever moaned about the weather, then you can count yourself lucky that you don't live on Jupiter. The majority of the planet is formed of hydrogen and helium gases. The clouds, however, are made up of ammonia ice crystals.

The temperature range on Jupiter is pretty incredible. The clouds that hover above the surface of the planet are a freezing -145 degrees Celsius (-229 degrees Fahrenheit), but as you move closer to the core it reaches a scorching 35,000 degrees Celsius (63,000 degrees Fahrenheit). And if that doesn't sound quite bad enough, then the weather conditions on the surface of the planet are almost guaranteed to put you off.

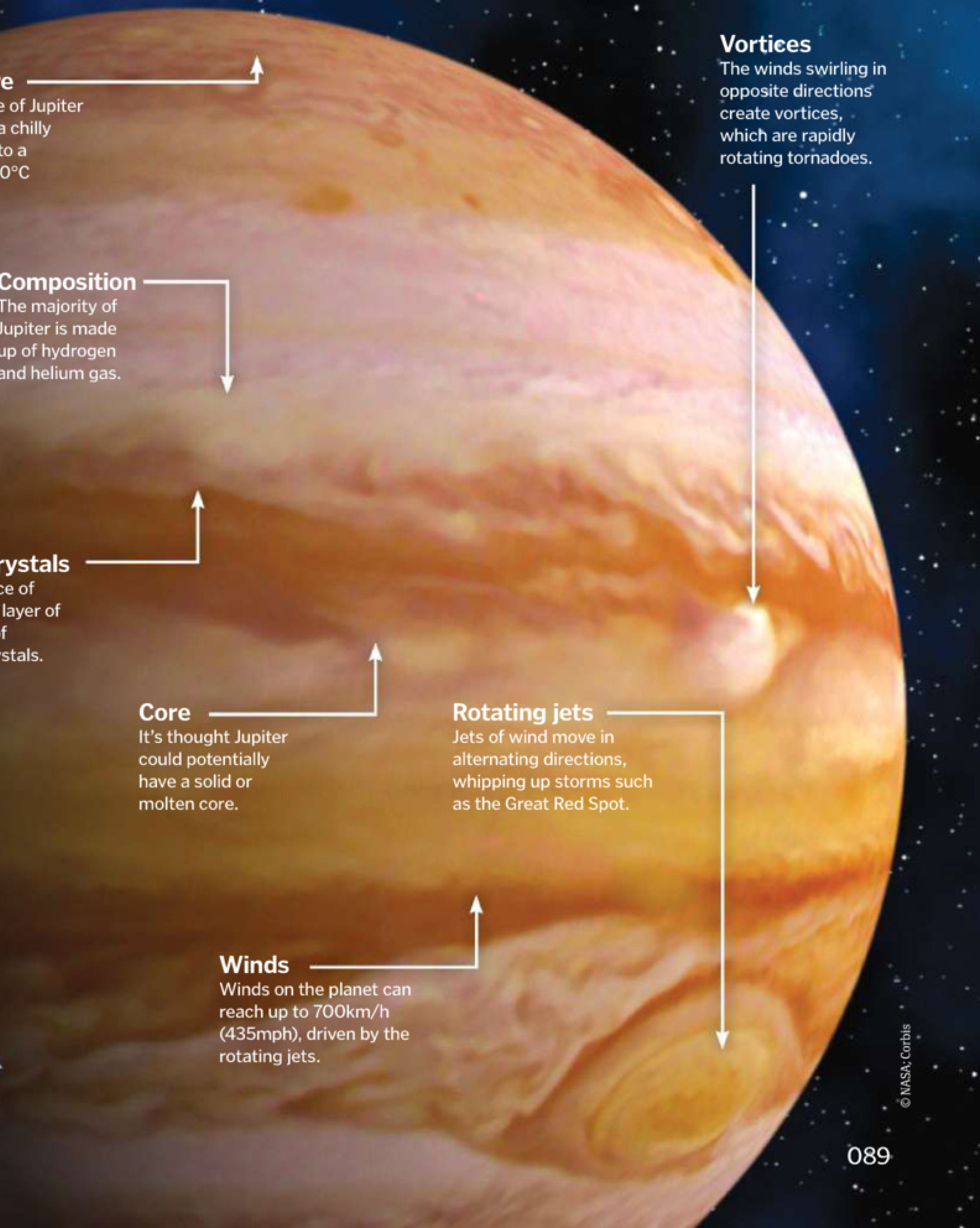
We spoke to expert Pedram Hassanzadeh, an Environmental Fellow at Harvard University: "The atmosphere of Jupiter has two prominent visible features", he explains. "These are strong winds that form multiple jets of alternating direction between the equator and the poles, and hundreds of hurricane-like swirling winds known as vortices. The average speed of the jets can be more than 360 kilometres (224 miles) per hour. For comparison, Earth has two prominent eastward jets in each hemisphere and their average speed is about 100 kilometres (62 miles) per hour."

If, having seen the wild temperature changes, the mind-boggling winds and dramatic tornadoes, you are still keen to visit Jupiter, Hassanzadeh has one more word of advice for any potential tourists: "Jupiter does not have a solid surface, which would make life on the planet kind of hard."

The Great Red Spot

One of the best-known features of Jupiter, apart from its size, is the Great Red Spot. First recorded in 1831 and consistently observed for more than 100 years, the weather system measures about 16,500 x 14,000 kilometres (10,250 x 8,700 miles). Hassanzadeh explains what the Great Red Spot actually is: "It consists of strong swirling winds with a maximum speed of 700 kilometres (435 miles) per hour. It's not clear how the Great Red Spot was created, but vortices are common in rapidly rotating environments such as the atmosphere of the gas giants."

The Great Red Spot is notable as it has been raging for centuries, much longer than any other similar space tornadoes. However, Hassanzadeh has a theory as to how it has kept going for so long: "It has been speculated that the Great Red Spot has survived by extracting potential energy from the atmosphere and the kinetic energy of the jets, along with absorbing smaller vortices."



Temperature The temperature of Jupiter can range from a chilly -145°C (-229°F) to a super-hot 35,000°C (63,000°F).

Vortices The winds swirling in opposite directions create vortices, which are rapidly rotating tornadoes.

Composition The majority of Jupiter is made up of hydrogen and helium gas.

Ammonia crystals Above the surface of Jupiter is a thick layer of cloud made up of ammonia ice crystals.

Core It's thought Jupiter could potentially have a solid or molten core.

Rotating jets Jets of wind move in alternating directions, whipping up storms such as the Great Red Spot.

Winds Winds on the planet can reach up to 700km/h (435mph), driven by the rotating jets.

© NASA; Corbis

Solar storms

Every 11 years our Sun reaches a peak of activity that makes its influence felt across the Solar System, but what causes it?

Even as you read this, enormous explosions are wracking our local star, 150 million kilometres (93 million miles) from Earth. Twisted lines of magnetic field are channelling hot gas far above the surface of the Sun, occasionally 'short-circuiting' to release incredible amounts of energy that fires out particles across space at up to 80 per cent the speed of light.

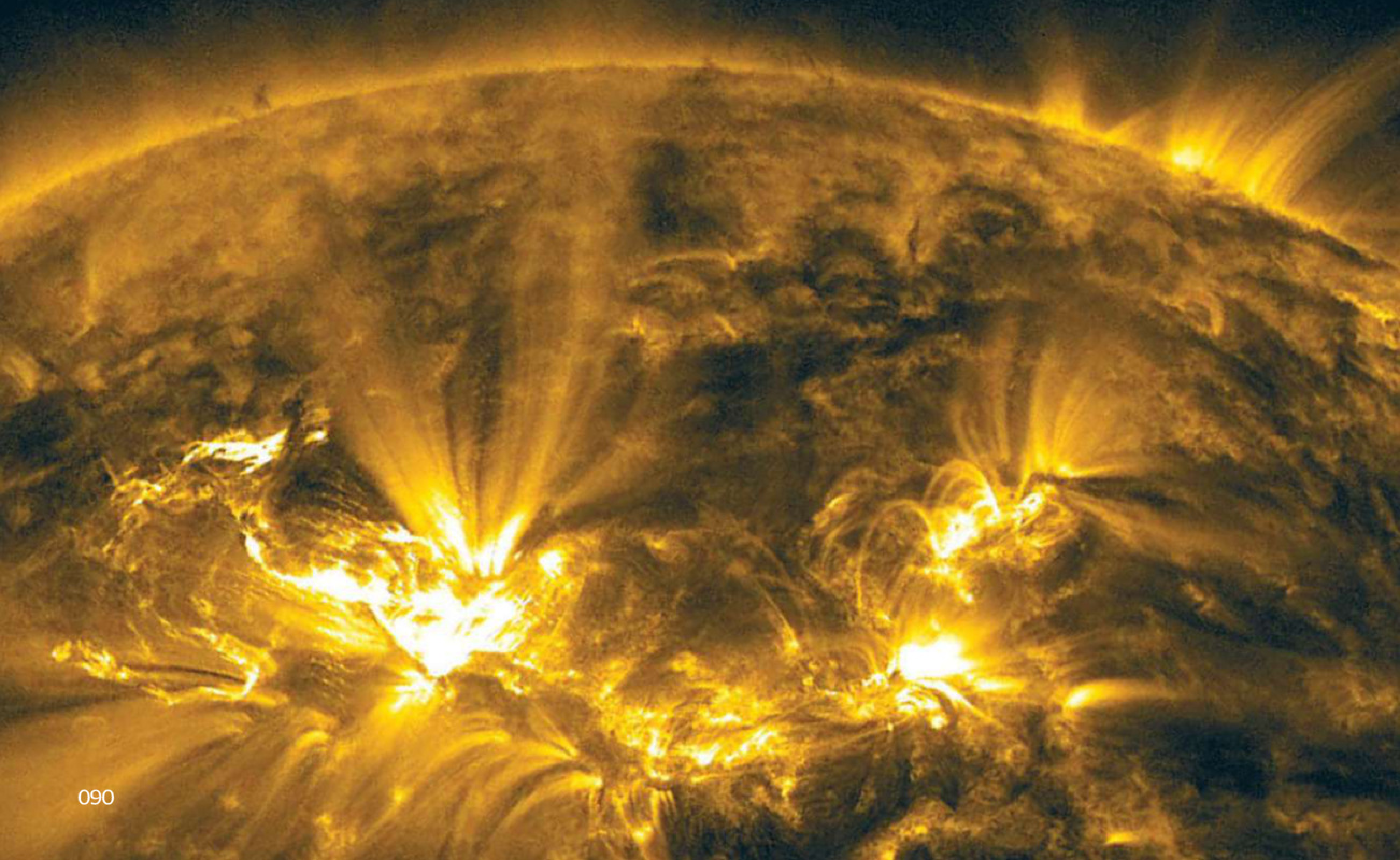
2013 marks the latest 'solar maximum', the centrepiece of an 11-year period of activity in the Sun's upper layers that is officially known as Solar Cycle 24. At its peak, the Sun's activity is expected to release epic levels of energy in bursts that will make themselves felt across the Solar System. While astronomers on Earth will watch eagerly for spectacular displays of the polar auroras (northern and southern lights), engineers will be on the alert for trouble. During the 1989 maximum, a solar storm triggered a blackout across Canada and north-east USA as it overloaded electricity grids, while a decade before, a similar event sent NASA's Skylab space station plunging back to Earth in a premature, uncontrolled descent.

Already in 2013, solar flares have briefly disrupted GPS satellite navigation signals and radio communications through their effects on the ionosphere – an upper region of our planet's atmosphere that is often used to send long-distance radio signals.

The solar maximum changes the Sun in a variety of ways. The number and size of sunspots on its visible surface is at its greatest, turning the bright orb into a mottled, blotchy disc of light when it is projected through safe viewing equipment. Seen via special filters, the disc of the Sun reveals bright loops around its edges, known as prominences, and dark streaks across its face, called filaments.

Prominences and filaments are, in fact, the same phenomenon, appearing bright against the background of space but dark against the hotter solar surface. Bright spots above the solar disc mark the locations of huge solar flares, and seen from space or during an eclipse, the Sun's outer atmosphere, or corona, is much bigger and brighter than normal.

Although for years we believed that the Sun's overall energy output changed very little throughout the cycle, in 2009 astronomers



RECORD BREAKERS
FLARE POWER

1 billion

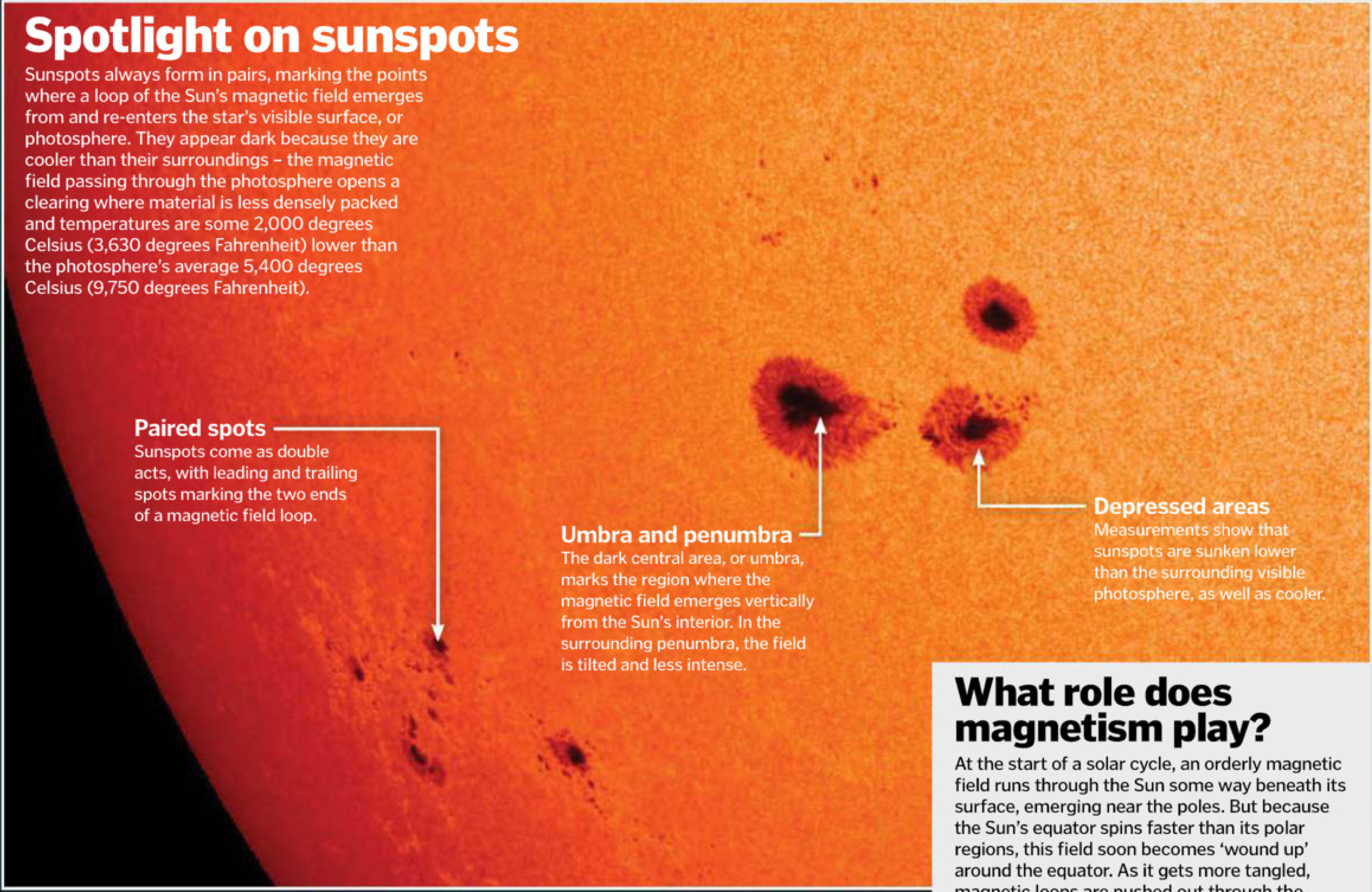
SOLAR FLARE ENERGY OUTPUT

The energy released in a solar flare is equivalent to over a billion megatons of TNT explosive – that's approximately one per cent of the Sun's total energy output per second.

DID YOU KNOW? *The 2003 'Halloween superflare' was so powerful that it overloaded the sensors attempting to measure it*

Spotlight on sunspots

Sunspots always form in pairs, marking the points where a loop of the Sun's magnetic field emerges from and re-enters the star's visible surface, or photosphere. They appear dark because they are cooler than their surroundings – the magnetic field passing through the photosphere opens a clearing where material is less densely packed and temperatures are some 2,000 degrees Celsius (3,630 degrees Fahrenheit) lower than the photosphere's average 5,400 degrees Celsius (9,750 degrees Fahrenheit).



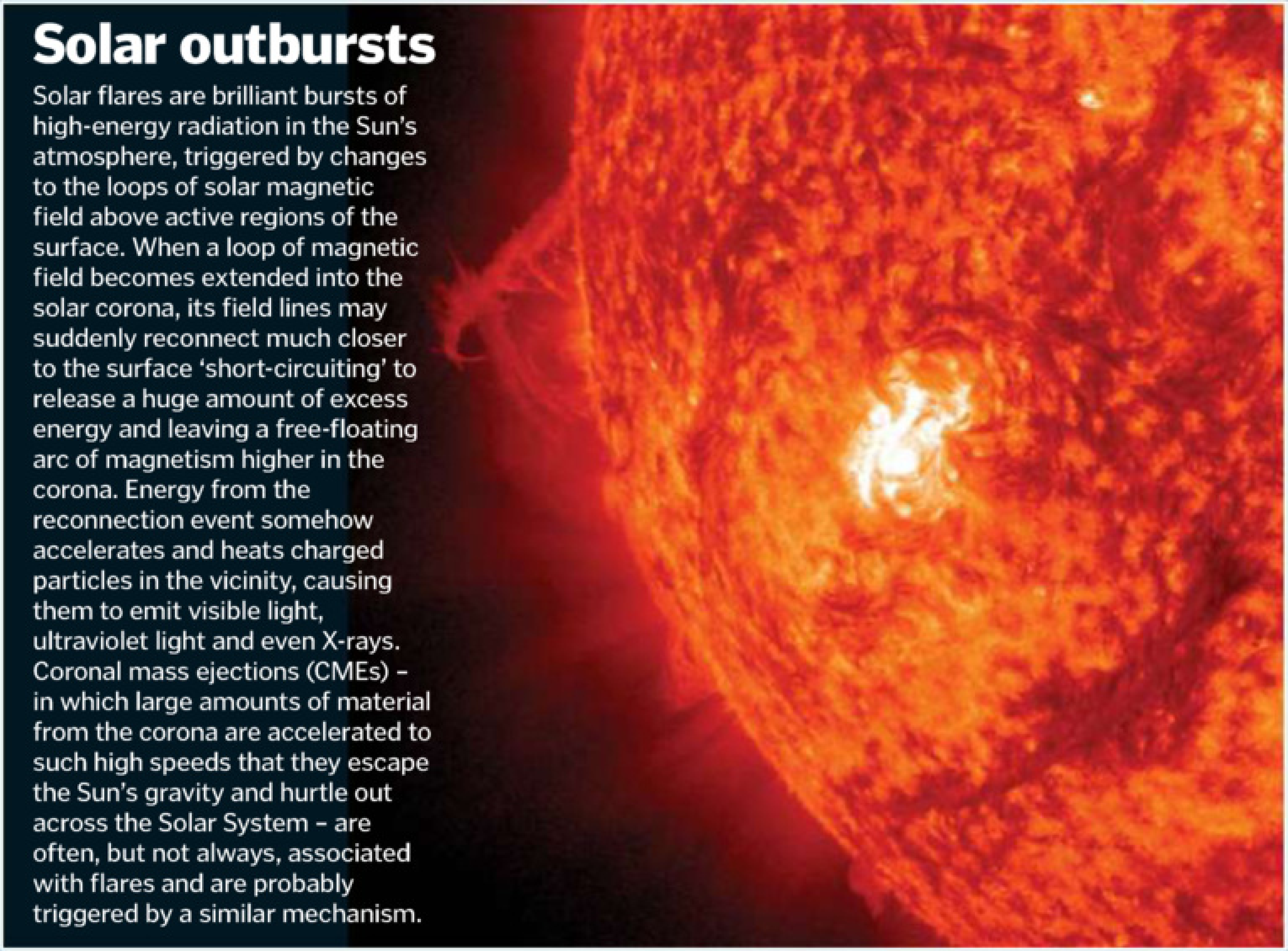
Paired spots
Sunspots come as double acts, with leading and trailing spots marking the two ends of a magnetic field loop.

Umbra and penumbra
The dark central area, or umbra, marks the region where the magnetic field emerges vertically from the Sun's interior. In the surrounding penumbra, the field is tilted and less intense.

Depressed areas
Measurements show that sunspots are sunken lower than the surrounding visible photosphere, as well as cooler.

Solar outbursts

Solar flares are brilliant bursts of high-energy radiation in the Sun's atmosphere, triggered by changes to the loops of solar magnetic field above active regions of the surface. When a loop of magnetic field becomes extended into the solar corona, its field lines may suddenly reconnect much closer to the surface 'short-circuiting' to release a huge amount of excess energy and leaving a free-floating arc of magnetism higher in the corona. Energy from the reconnection event somehow accelerates and heats charged particles in the vicinity, causing them to emit visible light, ultraviolet light and even X-rays. Coronal mass ejections (CMEs) – in which large amounts of material from the corona are accelerated to such high speeds that they escape the Sun's gravity and hurtle out across the Solar System – are often, but not always, associated with flares and are probably triggered by a similar mechanism.

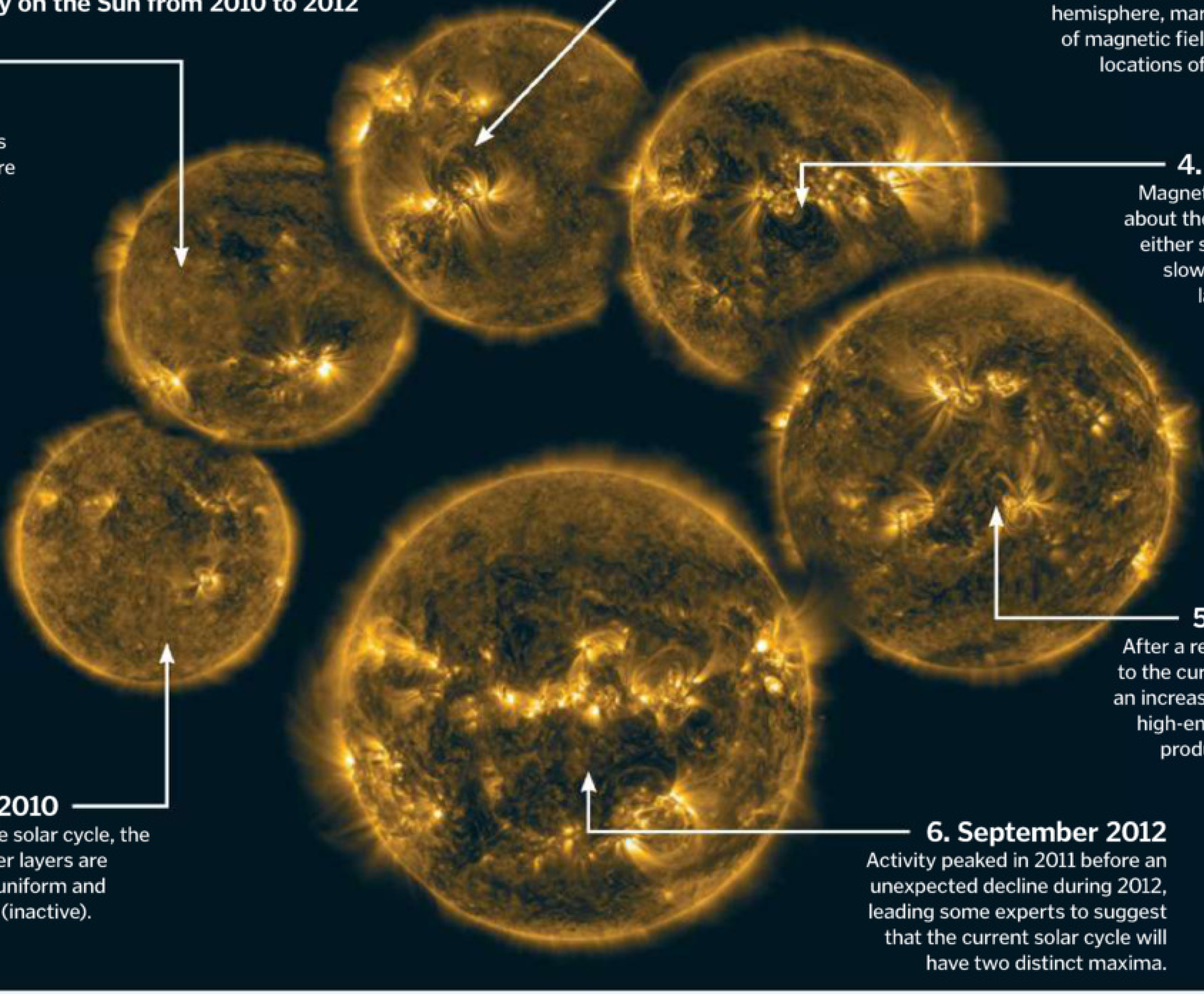


What role does magnetism play?

At the start of a solar cycle, an orderly magnetic field runs through the Sun some way beneath its surface, emerging near the poles. But because the Sun's equator spins faster than its polar regions, this field soon becomes 'wound up' around the equator. As it gets more tangled, magnetic loops are pushed out through the photosphere, creating sunspot pairs with one spot closer to the pole and another closer to the equator, opposite in polarity. Eventually, the field becomes so tangled up that magnetic regions on opposite sides of the equator start to cancel out. The field dwindles away to nothing, only to regenerate (with the opposite polarity) at the start of the next solar cycle after about 11 years.

Maximum in progress

This sequence of images from the SDO satellite charts developing activity on the Sun from 2010 to 2012



1. May 2010
Early in the solar cycle, the Sun's upper layers are relatively uniform and quiescent (inactive).

2. EUV view
Extreme UV (EUV) radiation reveals thin but intensely hot layers of the Sun's atmosphere above the surface that are usually invisible.

3. March 2011
By early-2011, bright hot regions appear in each hemisphere, marking loops of magnetic fields and the locations of sunspots.

4. Active bands
Magnetic disturbances lie about the same distance to either side of the equator, slowly moving to lower latitudes over time.

5. March 2012
After a relatively quiet start to the current cycle, there is an increase in the number of high-energy X-class flares produced in early-2012.

6. September 2012
Activity peaked in 2011 before an unexpected decline during 2012, leading some experts to suggest that the current solar cycle will have two distinct maxima.

revealed evidence for significant changes in its emission of ultraviolet radiation, which some think has the potential to affect Earth's climate.

Yet the solar maximum is just one phase in the overall solar cycle. At other times, the Sun is relatively quiet and free of sunspots and flares. The cycle was first documented in 1843 by German astronomer Samuel Heinrich Schwabe, after he spent 17 years recording the number and distribution of sunspots. Soon after, Swiss astronomer Johann Rudolf Wolf had traced the cycle as far back as 1745 using historical records, and introduced the numbering system that is still used to refer to different cycles.

Today the number and distribution of sunspots is often represented by the so-called 'butterfly diagram': the cycle starts off at solar minimum, with very few sunspots visible at fairly high latitudes on either side of the Sun's equator. Each individual spot may last a few days or weeks, but the pattern of distribution changes with time. Over several years, sunspots occur at lower latitudes and their number, size and intensity increase, reaching a peak at solar maximum. Over the next few years, as the spots draw closer to the equator, their numbers and intensity decline again.

Nobody really suspected that the sunspot cycle was accompanied by other activity until the mid-19th century, when Earth was buffeted by the biggest solar storm ever recorded.

English amateur astronomer Richard Carrington got the first hint of it on 1 September 1859, when he noted an intense white spot of light (what we'd now call a solar flare) on the disc of the Sun projected through his telescope onto a screen. Barely a day later, as clouds of material ejected from the Sun swept past Earth and interacted with our planet's magnetic field, intense auroras were seen all around the world. The northern lights (normally limited to polar skies) lit up the night as far south as the Caribbean, and people at higher latitudes were even able to read by the eerie glow.

The since-christened Carrington Event was an X-class solar flare (the most powerful type), accompanied by a coronal mass ejection (CME) – a wave of particles from the Sun's upper atmosphere superheated by the flare itself and directed straight towards Earth.

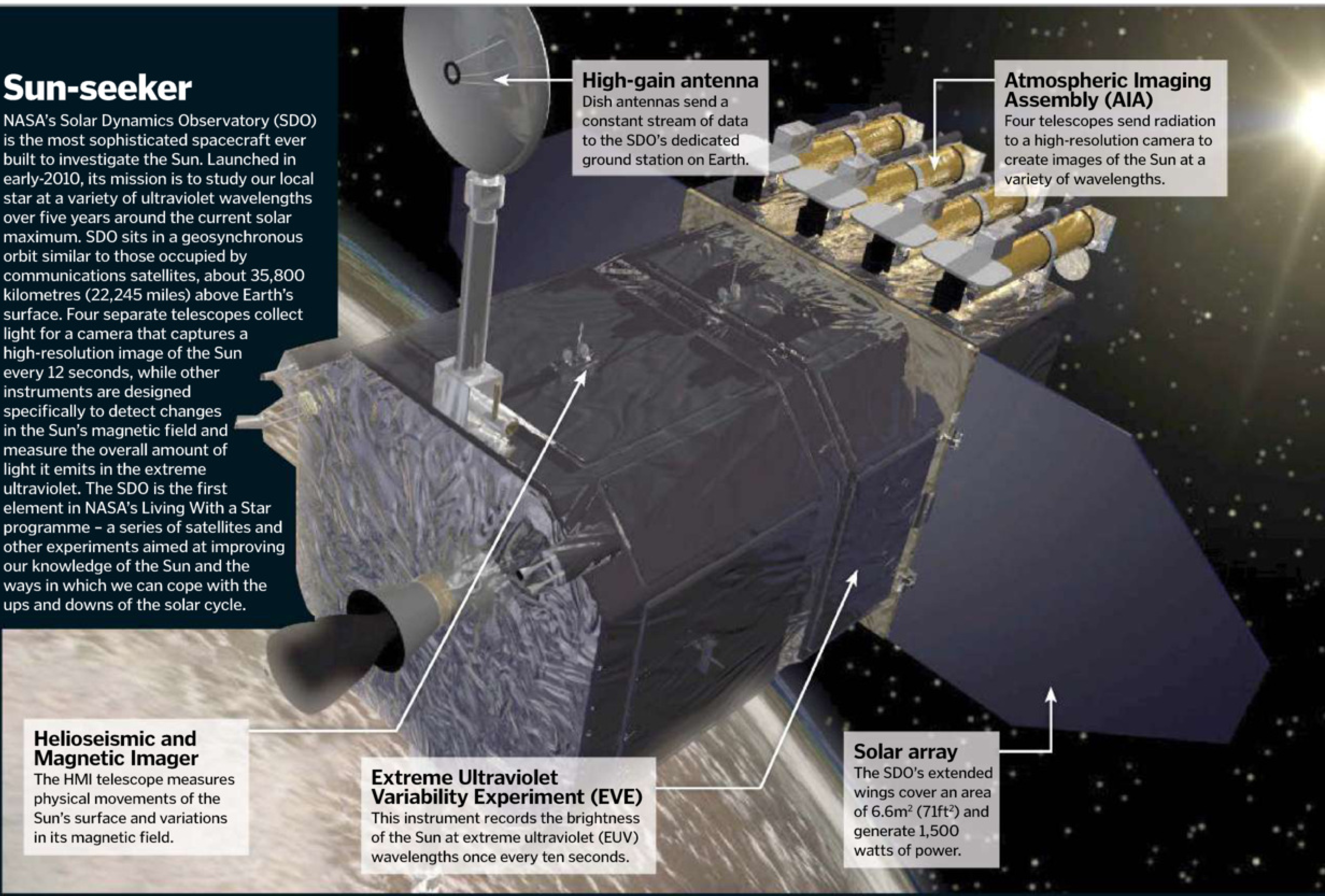
In addition to the spectacular light show, it also offered the first hint that solar storms could affect our technology even on the surface of Earth. Magnetometers picked up a sudden change in the magnetic field flowing through the atmosphere, and telegraph systems – the 19th-century equivalent of the internet, sending messages back and forth between Europe and America – suddenly went haywire, sometimes emitting visible sparks and giving their operators electric shocks. Not surprisingly, the Carrington Event is today acknowledged as the peak of a cycle (Solar Cycle 10).

Since Victorian times, we've learned a lot more about how the solar cycle works. In 1908, US astronomer George Ellery Hale showed that sunspots are associated with strong magnetic fields, and this proved to be the key to understanding the entire solar cycle.

DID YOU KNOW? NASA's SDO generates a CD's worth of information every 36 seconds

Sun-seeker

NASA's Solar Dynamics Observatory (SDO) is the most sophisticated spacecraft ever built to investigate the Sun. Launched in early-2010, its mission is to study our local star at a variety of ultraviolet wavelengths over five years around the current solar maximum. SDO sits in a geosynchronous orbit similar to those occupied by communications satellites, about 35,800 kilometres (22,245 miles) above Earth's surface. Four separate telescopes collect light for a camera that captures a high-resolution image of the Sun every 12 seconds, while other instruments are designed specifically to detect changes in the Sun's magnetic field and measure the overall amount of light it emits in the extreme ultraviolet. The SDO is the first element in NASA's Living With a Star programme – a series of satellites and other experiments aimed at improving our knowledge of the Sun and the ways in which we can cope with the ups and downs of the solar cycle.



High-gain antenna
Dish antennas send a constant stream of data to the SDO's dedicated ground station on Earth.

Atmospheric Imaging Assembly (AIA)
Four telescopes send radiation to a high-resolution camera to create images of the Sun at a variety of wavelengths.

Helioseismic and Magnetic Imager
The HMI telescope measures physical movements of the Sun's surface and variations in its magnetic field.

Extreme Ultraviolet Variability Experiment (EVE)
This instrument records the brightness of the Sun at extreme ultraviolet (EUV) wavelengths once every ten seconds.

Solar array
The SDO's extended wings cover an area of $6.6m^2$ ($71ft^2$) and generate 1,500 watts of power.

Most solar activity, it seems, is associated with loops of the Sun's magnetic field emerging through the visible surface, or photosphere. Sunspots form at either end of these loops, and prominences are caused by relatively dense but cool gas flowing along them. Flares and CMEs are created when the loops become stretched and distended, and then 'short-circuit' closer to the surface, releasing huge amounts of excess energy. The magnetic loops themselves are forced out of the photosphere by the Sun's complex rotation; unlike Earth's magnetic field, which originates in the churning molten iron of our planet's core, solar magnetism is created a little way below the surface by swirling currents of electrically charged plasma.

Because it isn't a solid body, the Sun rotates differentially – that is, moving at different speeds at different latitudes. While the equatorial regions spin roughly every 25 days, the high latitudes around the poles move much more slowly, taking around 35 days. This ensures the solar magnetic field becomes tangled and disrupted (see magnetism boxout on page 25). With each solar cycle, a fresh magnetic field is created and destroyed, only to regenerate again. One side-effect of this is that the Sun's magnetism 'flips' with the completion of every solar cycle – some experts even consider the true solar cycle to be around 22 years long, since that's how long it takes for the Sun to return to its original state.

But although we now understand the essential causes of the cycle and the solar maximum, we certainly don't know everything – the Sun is unpredictable at the best of times, and solar maxima vary greatly in their intensity. The current solar cycle, for instance, seems to be one of the weakest on record, with relatively low numbers of sunspots, while the previous Solar Cycle 23 was far more intense and gave rise to some of the largest solar flares ever recorded – though fortunately they were mostly directed away from Earth.

Cycles can vary significantly in length too, by around two years on either side of the 11-year average, and can even produce double-maxima separated by a couple of years. And sometimes the cycle can stop altogether, as happened during a period of low activity from 1645-1715 known as the Maunder Minimum. This event coincided with a series of exceptionally cold northern-hemisphere winters, since referred to as the Little Ice Age – perhaps caused in part to less UV radiation from the Sun reaching Earth.

With the potentially dangerous effects of CMEs hitting our world, and the possibility that the solar cycle can alter Earth's climate, it's little wonder astronomers are eager to learn more about the Sun. Satellites like NASA's Solar Dynamics Observatory (SDO) are studying the current solar maximum in unprecedented detail, while others such as the twin Stereo spacecraft are designed to give advance warning of major flares and CMEs on the far side of the star. As we find out more about the influence solar outbursts can have on Earth, it's ever-more important to keep tabs on the weather forecast from space. ✿

© NASA

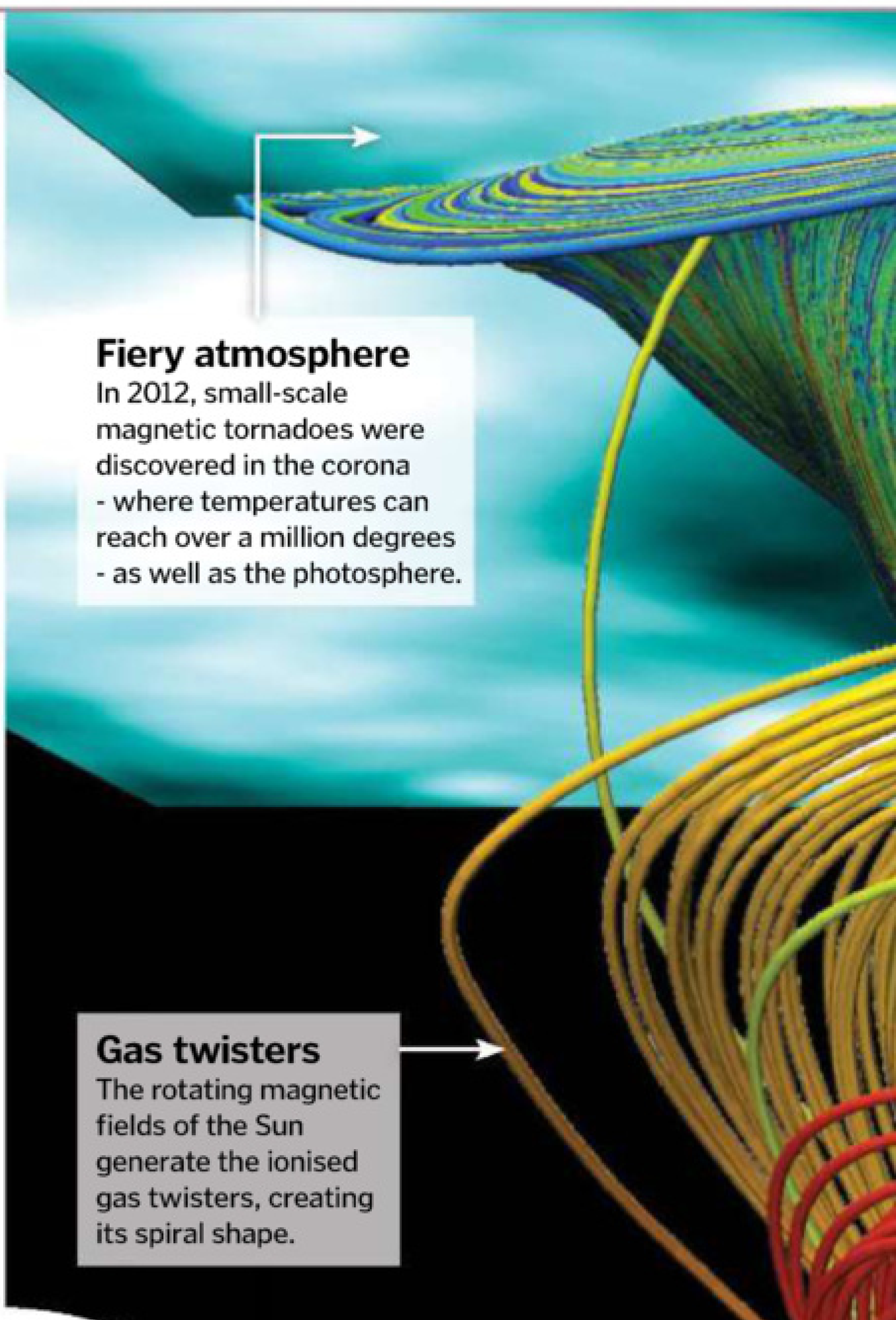
Solar tornadoes

The story behind twisters on the Sun, a thousand times larger than their Earthling counterparts

A gigantic sphere of hydrogen plasma (ionised gas), our Sun is by far the most dominant body in the Solar System and one of its most visually intense events is the solar tornado. These twisting magnetic fields are between 100 to 1,000 times larger than what we're used to on Earth and have been observed at a gigantic 70,000 kilometres (43,496 miles) tall. It has been calculated that over 11,000 of these phenomena are on the Sun's surface at any time and they are believed to potentially be the source of heating for the outer reaches of the Sun and could contribute to auroras on our planet.

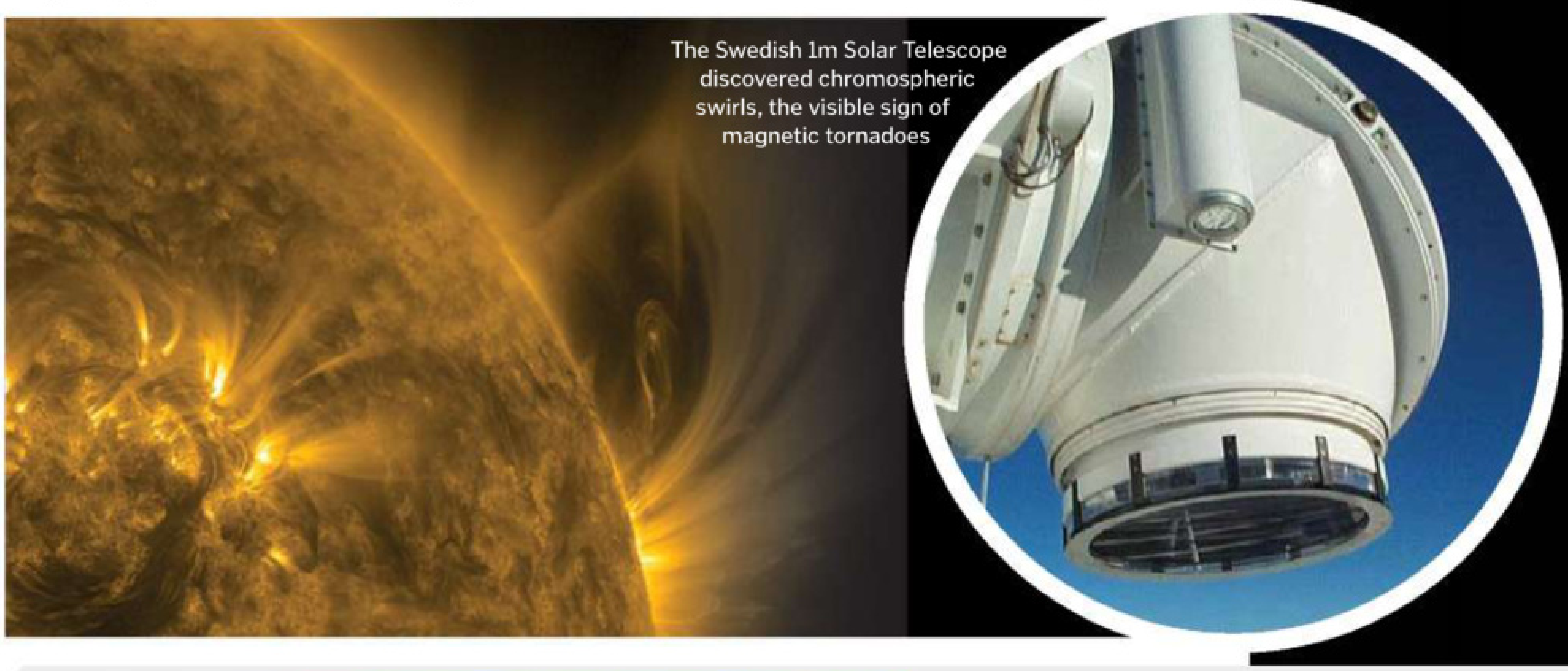
Solar tornadoes differ from Earth-based twisters because they are comprised of a magnetic field of plasma. They are more frequently spotted around the Sun's equator and poles, as this is where magnetism is most prominent. They exist on other stars as well as the Sun, burn at over a million degrees Celsius (1.8 million degrees Fahrenheit) and have swirling speeds of 10,000 kilometres (6,213 miles) per hour.

They appear in clusters and their main function is to heat the star's outer atmosphere by moving energy from the surface to the uppermost layer, the corona. They generate 100 to 300 watts per square metre (10.8 square feet) and are believed to be the reason for the corona's heat production, which has puzzled scientists and astronomers for generations. Observations from the Swedish 1m Solar Telescope in 2008 have increased our understanding of how nature heats magnetised plasma and how the 'chromospheric swirls' we can see are the result of the tornadoes.

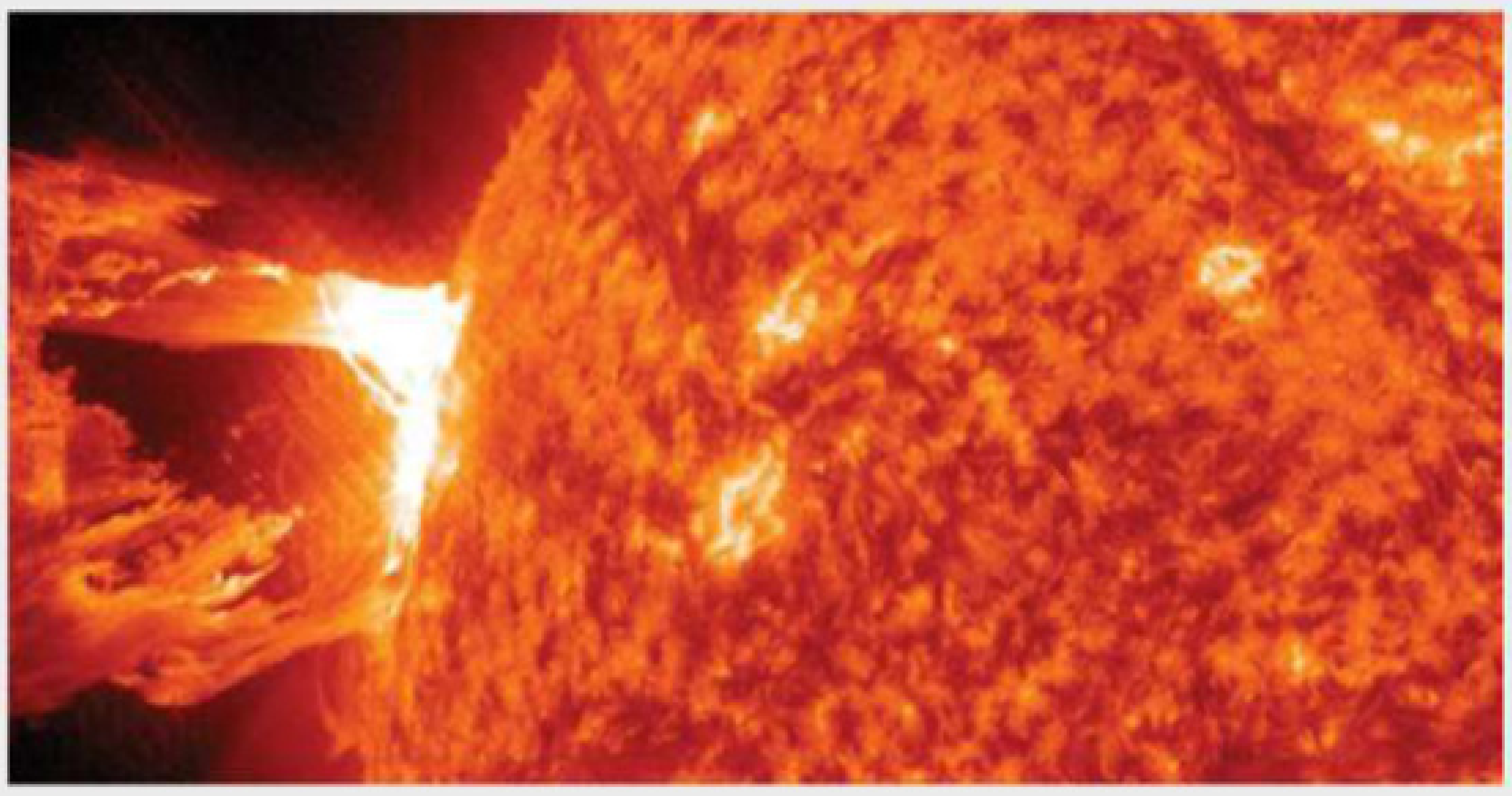


Fiery atmosphere
In 2012, small-scale magnetic tornadoes were discovered in the corona - where temperatures can reach over a million degrees - as well as the photosphere.

Gas twisters
The rotating magnetic fields of the Sun generate the ionised gas twisters, creating its spiral shape.



The Swedish 1m Solar Telescope discovered chromospheric swirls, the visible sign of magnetic tornadoes



Why is the corona so hot?

A curious anomaly of our nearest star is the fact that the corona, an aura of plasma surrounding the star, is hotter than many other areas of the Sun closer to its core. The corona can get up to two million degrees Celsius (3.6 million degrees Fahrenheit) while on the surface it is a measly 5,500 degrees Celsius (9,932 degrees Fahrenheit). Scientists and astronomers have long been perplexed by this but some new theories might explain why. Recent notions reason that heat is injected into the corona by wave heating from the core. As the corona is dominated by magnetic fields that are constantly connecting and engaging with each other, a convection zone is created, which releases high amounts of energy and heat. Solar tornadoes are linked to the plasma's astonishing heat levels as they contribute to coronal mass ejections (CME) and the solar winds in the Sun's atmosphere. To discover more, NASA has planned a mission known as the Solar Probe Plus, which is pencilled in for 2018.

5 TOP FACTS
SUN PHENOMENA

Solar flare
1 A massive magnetic energy release on the Sun's surface, a solar flare shows sudden concentrated brightness and emits huge amounts of radiation into the Solar System.

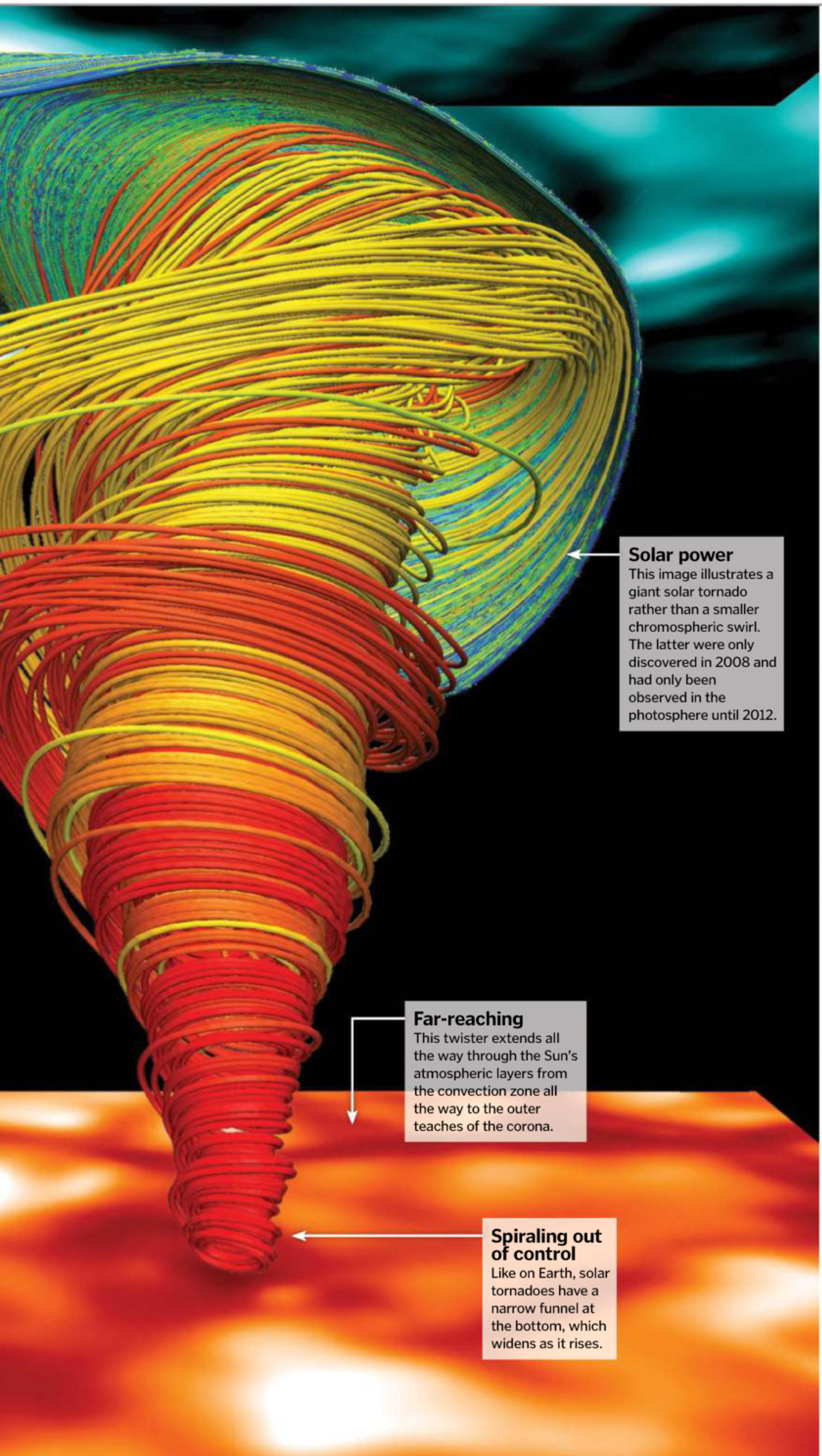
Coronal mass ejection
2 An eruption of solar wind caused by magnetic instabilities, CMEs can cause electrical problems to satellites and the Earth's magnetosphere.

Sunspot
3 A relatively dark and cool area of the photosphere, they have temperatures of around 3,500°C (6,330°F) and can reach over 50,000km (31,069mi) in diameter.

Geomagnetic storm
4 Caused by CMEs and solar flares, radiation-charged particles affect the Earth's magnetic field and cause auroras in the North and South Polar regions.

Solar prominence
5 Similar to a solar flare, solar prominences are loops of unstable plasma that extend from the surface to the corona, adding to the Sun's already vibrant appearance.

DID YOU KNOW? *There are two types of solar tornado: giant and small-scale magnetic. Experts are unsure whether they are linked*



Solar power
This image illustrates a giant solar tornado rather than a smaller chromospheric swirl. The latter were only discovered in 2008 and had only been observed in the photosphere until 2012.

Far-reaching
This twister extends all the way through the Sun's atmospheric layers from the convection zone all the way to the outer teaches of the corona.

Spiraling out of control
Like on Earth, solar tornadoes have a narrow funnel at the bottom, which widens as it rises.

Solar storm chaser

Dr Sven Wedemeyer-Böhm from the Institute of Theoretical Astrophysics explains more

How similar are solar tornadoes to tornadoes on Earth?
Aside from the visible appearance, tornadoes on Earth and on the Sun are very different phenomena. In both cases, the tornado funnel is narrow at the bottom and widens with height in the atmosphere. Particles inside tornadoes are forced to move in spirals. Tornadoes on Earth occur as a result of temperature and gas pressure differences and strong shear winds. Solar tornadoes are generated by rotating magnetic field structures, which force the plasma, ie the ionised gas, to move in spirals.

How do solar tornadoes contribute to auroras on Earth?
It has been speculated that giant tornadoes may serve as a possible trigger of solar eruptions, where they build up a magnetic field structure until it destabilises and erupts. As a consequence, ionised gas could get ejected towards Earth, which would then contribute to auroras. However, as of now, there's no direct connection confirmed.

Do you know about future planned missions to investigate this phenomenon?
There are missions such as Solar Orbiter and Solar-C, which may fly in foreseeable future. There will be also some major progress with ground-based observatories with the 4-m Daniel K Inouye Solar Telescope (DKIST, formerly the Advanced Technology Solar Telescope, ATST), which is currently built on Hawaii, and possibly the 4-m European Solar Telescope (EST), which may be built in the future. These new instruments will allow for an even closer look at our Sun and will enable us to answer the many open questions that we still have about solar tornadoes.

What is the primary difference between giant solar tornadoes and small-scale magnetic tornadoes?
It is currently not clear if these are different phenomena or not. Small-scale magnetic tornadoes have only been observed from the top so far, ie in the middle of the solar disk, whereas giant tornadoes are seen more towards the limb of the Sun, in other words: from the side. In general, magnetic tornadoes tend to have somewhat smaller diameters than giant tornadoes but it is too early to draw solid conclusions.

What is the primary difference between giant solar tornadoes and small-scale magnetic tornadoes?
There are still many questions concerning solar tornadoes and we hope to address some of the most important aspects during the next three years in a project, which has just started at the University of Oslo in collaboration with international experts.

© SST/ISP; Wedemeyer-Böhm et al; NASA/SDO

Ancient volcanoes contributed to Venus's atmosphere and might still be erupting today

© ESA/AOES Medialab

Why is Venus so hot?

The hottest planet in the solar system's runaway greenhouse effect explained

With a surface temperature of 462°C, Venus is definitely not the ideal holiday destination. Its unique climate contributes to the most powerful greenhouse effect in the solar system, with an atmospheric pressure 92 times that of Earth. It's thought that billions of years ago the planet was much like Earth, with a significantly lower temperature and vast oceans of water. However, its proximity to the Sun meant this liquid water evaporated into the atmosphere. This in turn sublimated carbon in rocks and mixed with the oxygen in the atmosphere to form carbon dioxide, which now accounts for about 95% of the atmosphere. This is known as a 'runaway greenhouse effect', as the creation of more carbon dioxide in the atmosphere released more carbon from the ground, repeating the process. Only 10% of incoming solar radiation reaches the surface, but almost all of this stays trapped inside the atmosphere, giving rise to a temperature difference of almost 500°C between the surface and the cloud layer.

Solar tsunamis

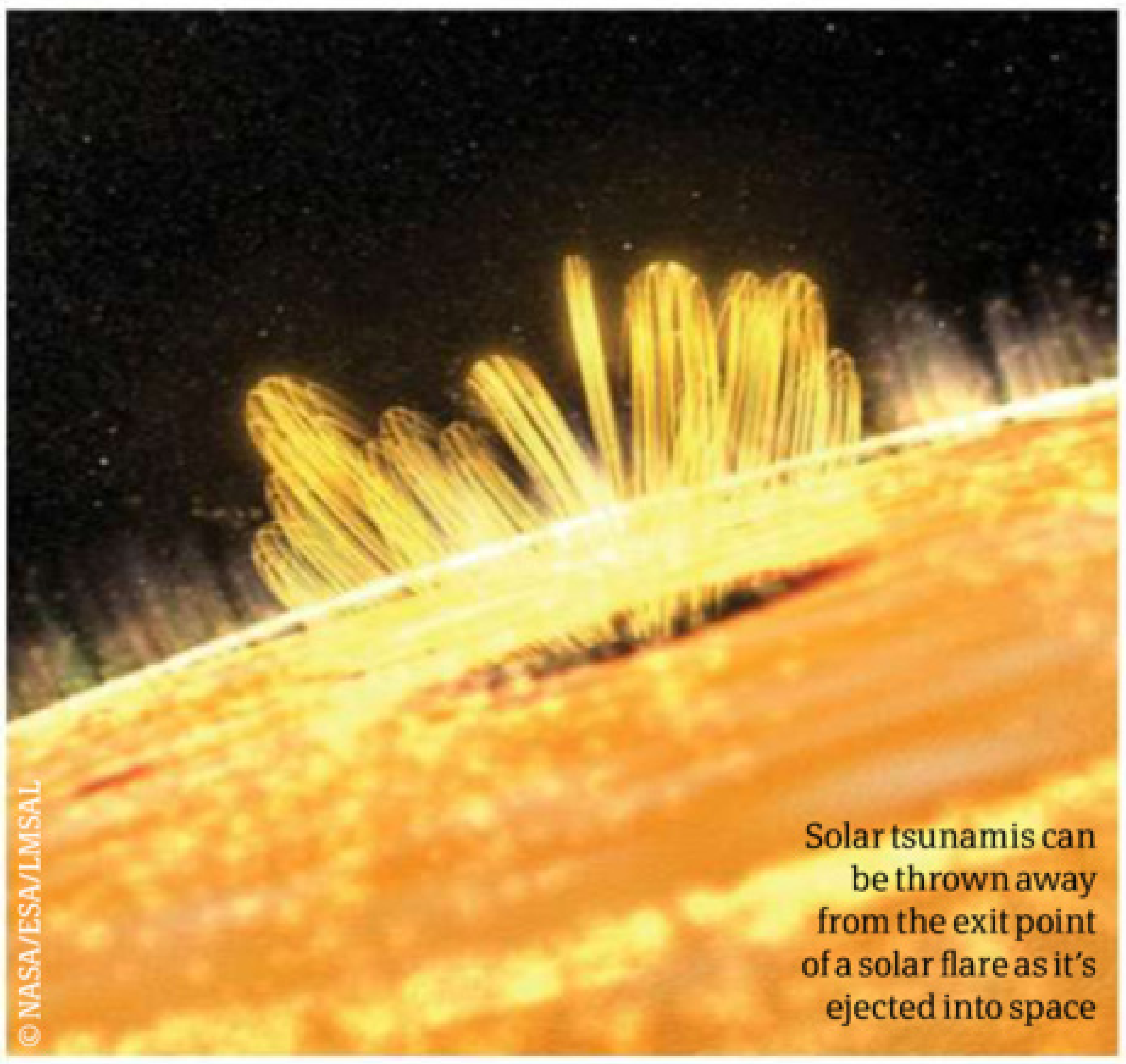
The mega-waves of energy that tear across the Sun

Solar tsunamis, also known as Moreton waves or fast-mode magnetohydrodynamic (MHD) waves, are surges of material sent crashing across the Sun as the result of a solar flare being launched into space. They can travel up to an incredible 1.6 million kilometres (1 million miles) per hour.

Solar tsunamis are made of hot plasma and magnetic energy. The first was observed by Gail Moreton in 1959, and since then several more studies have been conducted on the phenomenon by the Solar and Heliospheric Observatory (SOHO) and the Solar Terrestrial Relations Observatory (STEREO) spacecraft.

The tsunamis are formed when the Sun emits a coronal mass ejection (CME), a massive burst of solar wind commonly associated with solar flares. Around the ejection point a circular wave extends outwards in all directions travelling at a super-fast rate.

In February 2009, the two STEREO spacecraft watched as a billion-ton cloud of gas was hurled off the surface of the Sun from a CME. The result was a solar tsunami that towered 100,000 kilometres (60,000 miles) high speeding across the star's surface at about 900,000 kilometres (560,000 miles) per hour. Estimates indicate it contained the same energy as 2.4 million megatons of TNT.



Solar tsunamis can be thrown away from the exit point of a solar flare as it's ejected into space

© NASA/ESA/LMSAL

© NASA

What is space weather?

There's no atmosphere in space, but it still has weather

Just because we have an atmosphere here on Earth, it doesn't mean we have a monopoly on weather. Outer space has weather of sorts too, and it's driven by the same source – the Sun. When we refer to space weather, we're generally talking about what's happening on the Sun and what the solar wind is doing. At key points during its 11-year solar cycle, the Sun releases billions of tons of solar material in what is called a coronal mass ejection (CME), which can cause huge magnetic storms around the Earth. This can make for an impressive northern and southern lights displays known as auroras.

Comet storms

Discover how these icy rocks once rained down on the Solar System – and why another comet storm is on the cards

RECORD BREAKERS
IT'S A LONG TALE

150MN KM

LONGEST CELESTIAL OBJECT

A comet's ion tail can extend for 150 million kilometres (93 million miles) – about the distance from the Sun to the Earth – making them the longest objects in the Solar System.

DID YOU KNOW? *In late-2013 C/2012 S1 (aka Comet ISON) could light up our night skies as it rounds the Sun*

Around 4 billion years ago, our Solar System was just beginning to settle down after its very turbulent genesis. The dust and gas surrounding the Sun had formed into the eight major planets, and in turn the planets were starting to stabilise in their orbits.

However, at some point around this time, something caused a huge comet storm in the Solar System. Over a period of about 200 million years – known as the Late Heavy Bombardment (LHB) – the planets and their moons were pelted by comets and other rocky objects from the outer edges of the Solar System. This comet storm is believed to be responsible for many of the craters we see on bodies like the Moon today, and could even have been the progenitor of life on Earth.

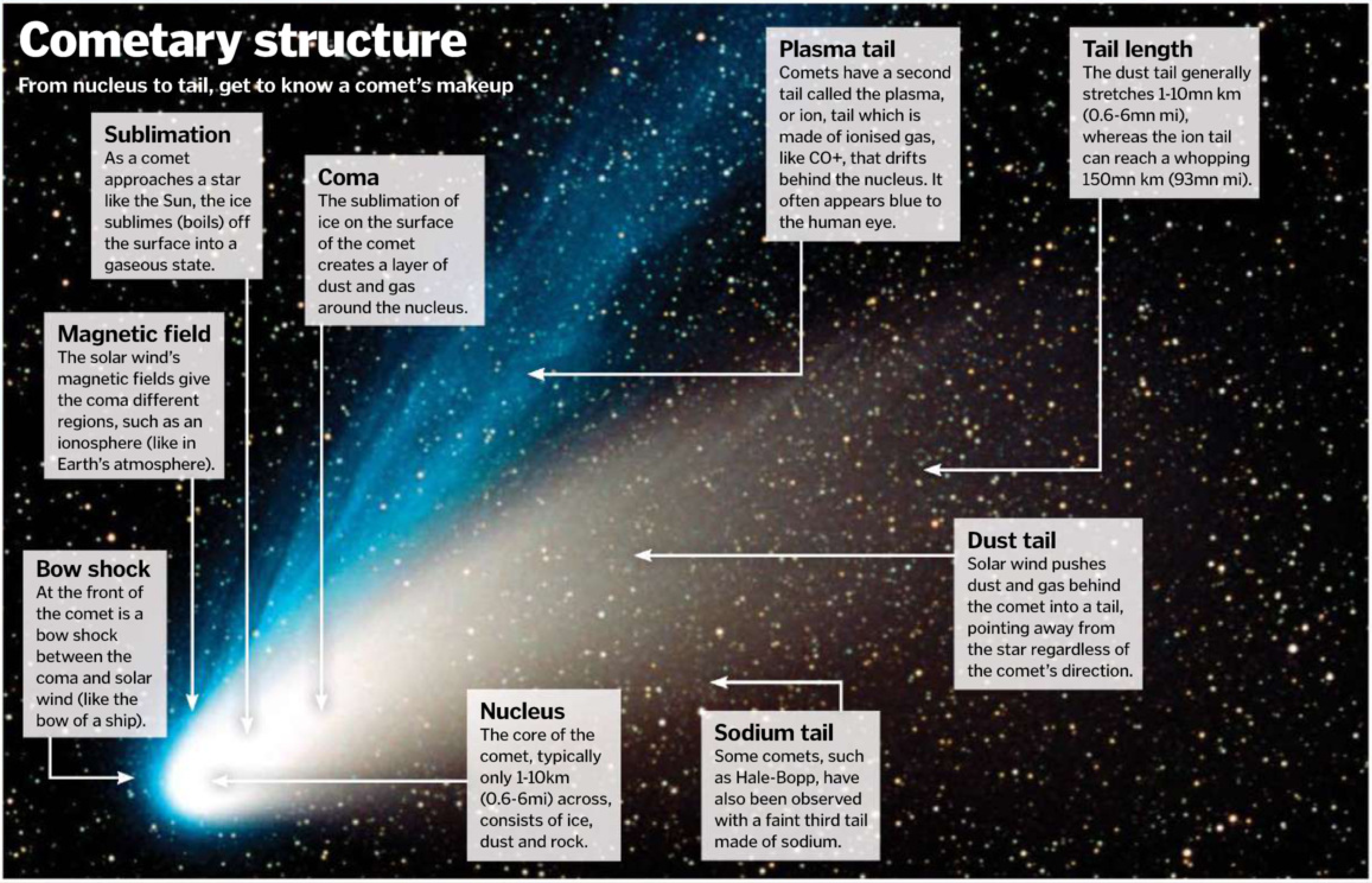
One of the key pieces of evidence we have for the LHB period was discovered during the Apollo missions. Lunar astronauts returned samples of rock which suggested that most impact melt rock on the Moon formed within a short period of time 4-3.8 billion years ago. While it's not conclusive, it's the best evidence we have that indicates a blitz of comets in our young planetary system.

The exact cause of this cosmic strike, however, is up for debate. The most likely theory is that the gas giants – mainly Jupiter and Saturn – migrated slightly in their orbits. This would have made the outer Solar System highly unstable, either pulling comets in from the outer reaches or from a now depleted inner band of the Asteroid Belt.

Another possibility is that the gas giants Uranus and Neptune formed much more slowly than the other planets, which would have meant that the outer Solar System had a relatively low density of material until they developed, allowing more rogue objects to make their way towards the Sun. It is the former theory, however, that carries more weight with space scientists at this time.

What we do know for certain is that something must have caused a sudden barrage of comets to enter the Solar System, and our current understanding is that there are potentially billions more with the potential to once again cause havoc.

Comets originate from one of two places: the Kuiper Belt and the Oort Cloud. The former is a region of space beyond Neptune, between 30 and 50 AU from the Sun (one astronomical unit – AU – is the



Cometary structure

From nucleus to tail, get to know a comet's makeup

Sublimation
As a comet approaches a star like the Sun, the ice sublimes (boils) off the surface into a gaseous state.

Coma
The sublimation of ice on the surface of the comet creates a layer of dust and gas around the nucleus.

Plasma tail
Comets have a second tail called the plasma, or ion, tail which is made of ionised gas, like CO+, that drifts behind the nucleus. It often appears blue to the human eye.

Tail length
The dust tail generally stretches 1-10mn km (0.6-6mn mi), whereas the ion tail can reach a whopping 150mn km (93mn mi).

Magnetic field
The solar wind's magnetic fields give the coma different regions, such as an ionosphere (like in Earth's atmosphere).

Dust tail
Solar wind pushes dust and gas behind the comet into a tail, pointing away from the star regardless of the comet's direction.

Bow shock
At the front of the comet is a bow shock between the coma and solar wind (like the bow of a ship).

Nucleus
The core of the comet, typically only 1-10km (0.6-6mi) across, consists of ice, dust and rock.

Sodium tail
Some comets, such as Hale-Bopp, have also been observed with a faint third tail made of sodium.

distance from Earth to the Sun), which contains many small bodies left over from the formation of the Solar System. It's a bit like the Asteroid Belt, but up to 200 times more massive, and unlike the Asteroid Belt it also plays host to comets. Those that come from the Kuiper Belt are known as short-period comets, like Halley's. This means that they typically swing through the Solar System on orbital periods no longer than 200 years.

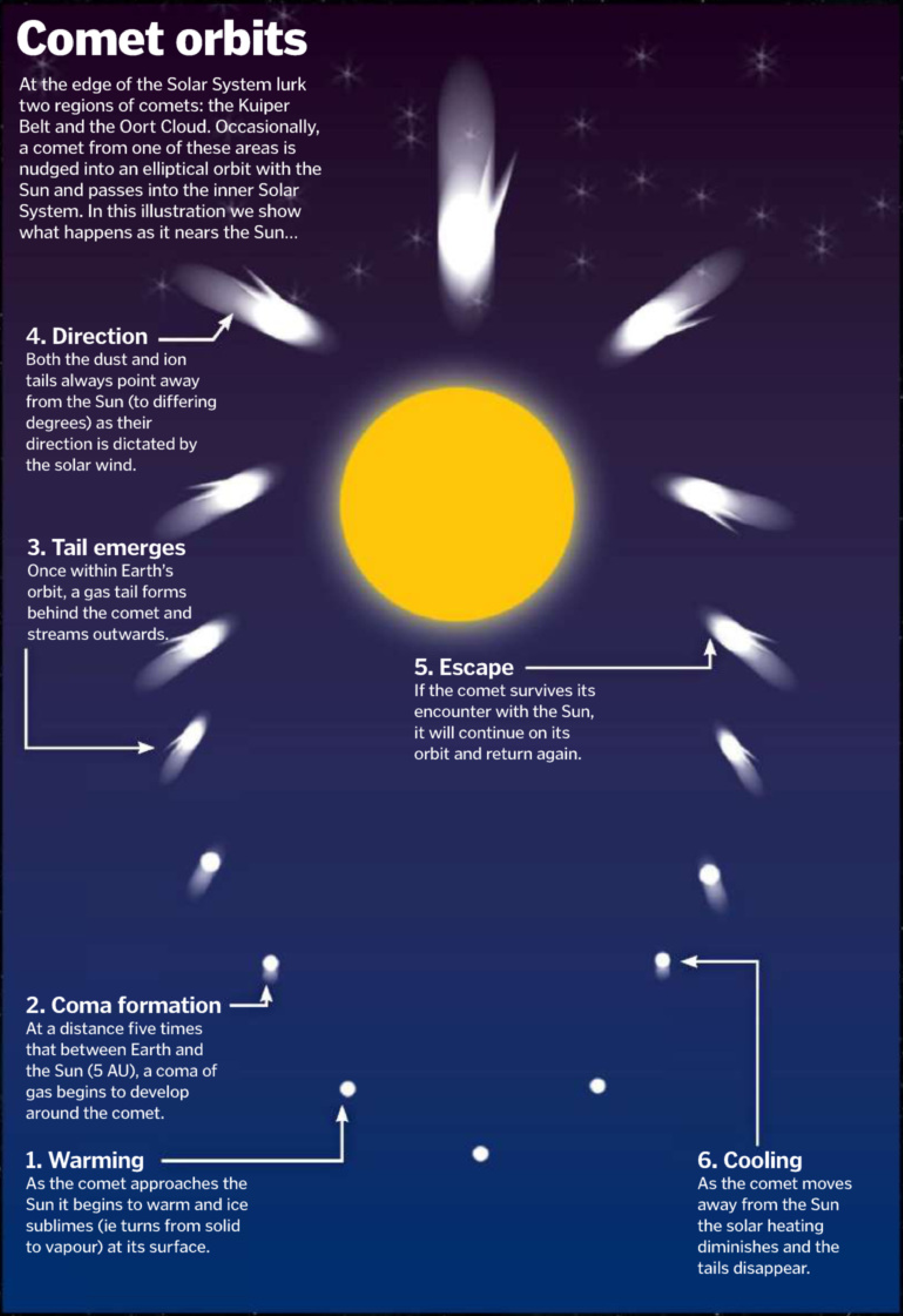
By comparison, the Oort Cloud is much farther away, about 50,000 AU (or 0.8 light years) from the Sun. It is thought to be the starting point of long-period comets, like Hale-Bopp – those that pass through the Solar System with orbital periods in the thousands of years, or possibly their path is so elliptical that they never return. We haven't ever directly observed this cloud, but the appearance of long-period comets from seemingly all portions of the sky suggests there must be some distant reservoir of these objects out in the galaxy.

The other major difference between these two regions is the number of objects they contain. While the Kuiper Belt is thought to play host to hundreds of thousands to millions of these icy rocks (known as Kuiper Belt objects, or KBOs), the Oort Cloud could be home to billions.

What this means for us is that these two vast regions have enough firepower to decimate pretty much every celestial body in the Solar System, but thankfully most of their objects are in stable positions, and only occasionally do a few venture into the Solar System. As explained earlier, this is what is thought to have happened 4 billion years ago but on a much larger scale; something disturbed the outer Solar System, sending a comet storm careering inwards and pummelling anything in its path. But could we really experience another period of bombardment like this?

Our Sun is believed to pass about 200,000 AU from another star every 2 million years, which may be the cause of stray comets being flung into the Solar System from the Kuiper Belt and the Oort Cloud. 1.5 million years from now, however, an orange dwarf star known as Gliese 710 could pass considerably closer to the Sun – possibly as near as 50,000 AU – which would see it pass through the Oort Cloud. Such an event, if it did occur, would be

Comet orbits



At the edge of the Solar System lurk two regions of comets: the Kuiper Belt and the Oort Cloud. Occasionally, a comet from one of these areas is nudged into an elliptical orbit with the Sun and passes into the inner Solar System. In this illustration we show what happens as it nears the Sun…

1. Warming
As the comet approaches the Sun it begins to warm and ice sublimes (ie turns from solid to vapour) at its surface.

2. Coma formation
At a distance five times that between Earth and the Sun (5 AU), a coma of gas begins to develop around the comet.

3. Tail emerges
Once within Earth's orbit, a gas tail forms behind the comet and streams outwards.

4. Direction
Both the dust and ion tails always point away from the Sun (to differing degrees) as their direction is dictated by the solar wind.

5. Escape
If the comet survives its encounter with the Sun, it will continue on its orbit and return again.

6. Cooling
As the comet moves away from the Sun the solar heating diminishes and the tails disappear.

Comets over time

A few milestone events involving comets on a crash course with other bodies

~4bn years ago (BYA)

LHB period
Possibly the interaction of the gas giants fires comets into the inner Solar System, instigating the Late Heavy Bombardment (LHB).

3.8 BYA

Bombardment ends
After 200 million years the bombardment of the Solar System ends, with most comets now remaining in the distant Oort Cloud.

July 1994

Shoemaker-Levy 9
This stray comet breaks apart and impacts Jupiter, the first such event witnessed by humans (pictured right).

DID YOU KNOW? *We know of a few thousand comets, but there could be billions more in the outer Solar System*

catastrophic. The gravitational pull of the star would send the Oort Cloud into disarray, and it's likely that many objects would be sent into the Solar System. After a close encounter such as this, another period of comet showers is likely. If the Oort Cloud is as vast and populated as we think, then we are always going to be under threat from some gravitational disturbance that could push those icy bodies towards our world.

It's not just in our Solar System where comet storms are thought to have occurred though. In July 2012, NASA's Spitzer Space Telescope detected signs of a storm similar to the LHB period in a young alien planetary system around the star Eta Corvi about 60 light years from us. The telescope spotted a band of dust around this bright star close enough to be near any planets in the system, which suggests that some sort of impact occurred in this 1-billion-year-old extrasolar system. It is likely that this system is right now undergoing the same sort of comet storm we experienced 4 billion years ago.

Of course, aside from these massive comet storms where thousands of objects enter a system at any one time, we're also susceptible to much smaller 'flurries'. When a comet enters the Solar System, the heat and gravitational pull of the Sun can cause it to break apart. If a comet approaches Earth, it will either burn up in the atmosphere or, in rare cases, hit the surface. We know of several such impact events that were likely the result of comets, including the impact that ended the age of the dinosaurs 65 million years ago and the Tunguska event in 1908 when a comet exploded over part of Russia and flattened an unpopulated area 2,150 square kilometres (830 square miles) in size.

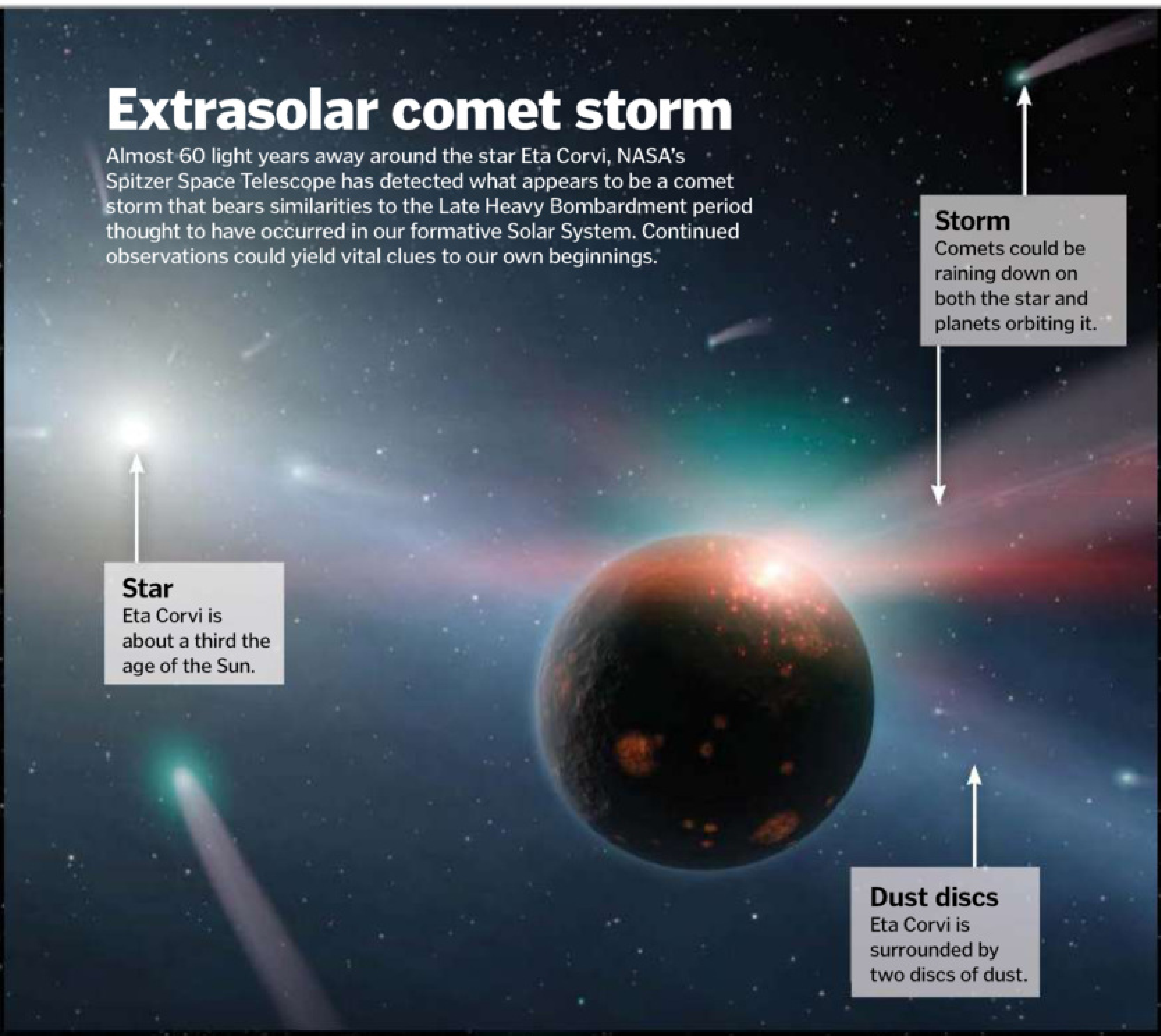
Most meteor showers seen from Earth are also the result of comets. They are usually caused by Earth passing through the tail of a comet, with its fragments then burning up in the atmosphere. Such events are minuscule compared to the LHB, but they're a constant reminder of comets' presence.

Owing to the number of comets, and their speed as they approach the Sun, it's impossible for us to track every single one. However, we are able to keep an eye on most that enter the inner Solar System, highlighted by the arrival of Comet ISON in November 2013 which could outshine the Moon in our night skies as it grazes the Sun.

By continuing to observe extrasolar systems though, we might be able to glean more information about the comet storm that pounded our Solar System 4 billion years ago during the Late Heavy Bombardment. Further evidence of this event could provide us with vital clues to our past, as well as give us an insight into what might happen to our Solar System in the future. ✽

Extrasolar comet storm

Almost 60 light years away around the star Eta Corvi, NASA's Spitzer Space Telescope has detected what appears to be a comet storm that bears similarities to the Late Heavy Bombardment period thought to have occurred in our formative Solar System. Continued observations could yield vital clues to our own beginnings.



Storm
Comets could be raining down on both the star and planets orbiting it.

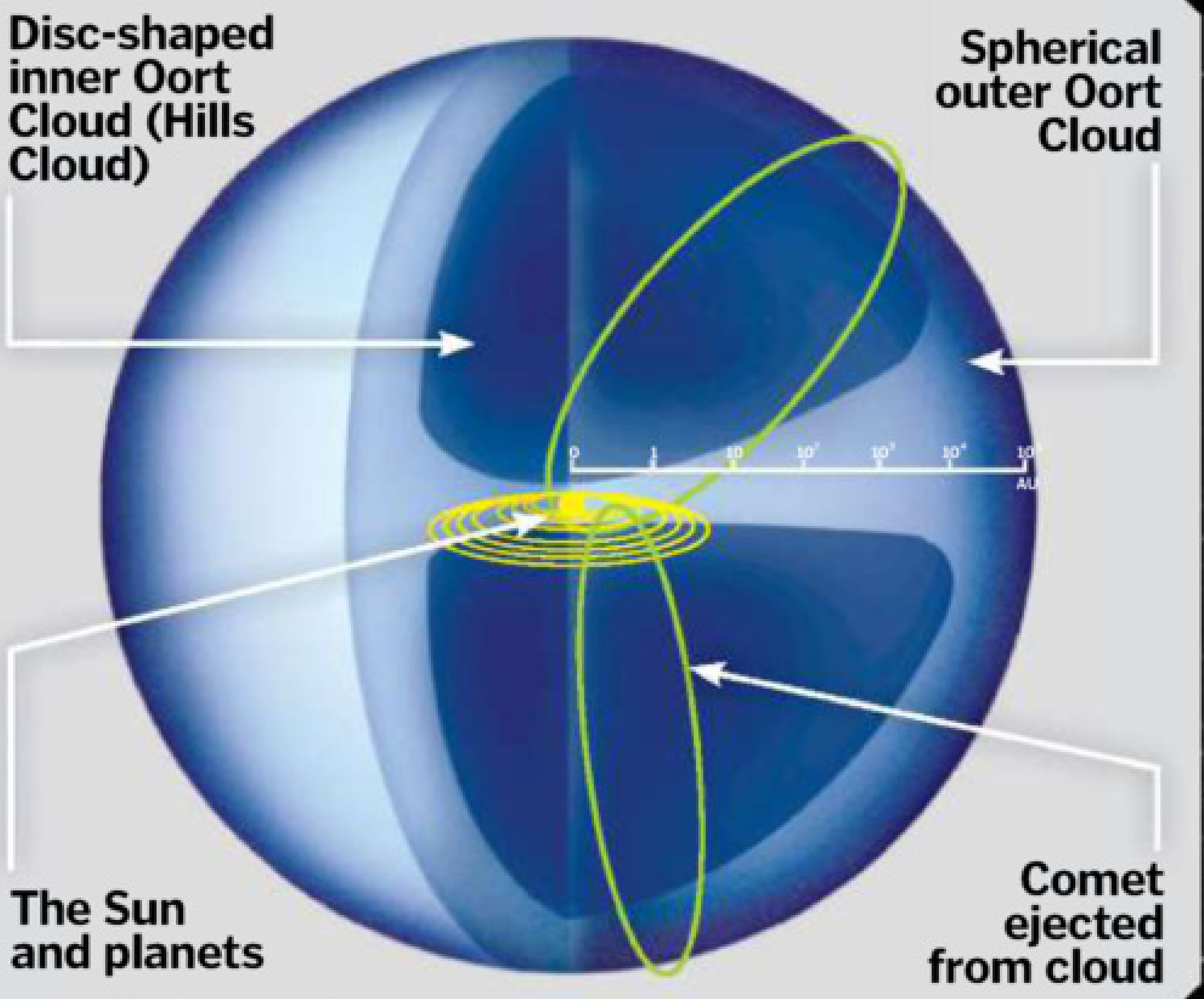
Star
Eta Corvi is about a third the age of the Sun.

Dust discs
Eta Corvi is surrounded by two discs of dust.

What is the Oort Cloud?

Approximately 50,000 times farther than the orbit of Earth around the Sun – or almost a light year away – it is thought that there is a region of rocks made of ices like water, ammonia and methane surrounding the Solar System called the Oort Cloud.

This area, a quarter of the distance to the next nearest star Proxima Centauri, could be home to billions of comets left over from the formation of the Solar System and ejected into its outer reaches. Periodically a comet will enter the Solar System, and most of these are believed to originate in this vast region of our galaxy.


Disc-shaped inner Oort Cloud (Hills Cloud)
Spherical outer Oort Cloud
AU
The Sun and planets
Comet ejected from cloud

December 2010

Solar comets
Astronomers detect 25 comets diving into the Sun over just nine days.

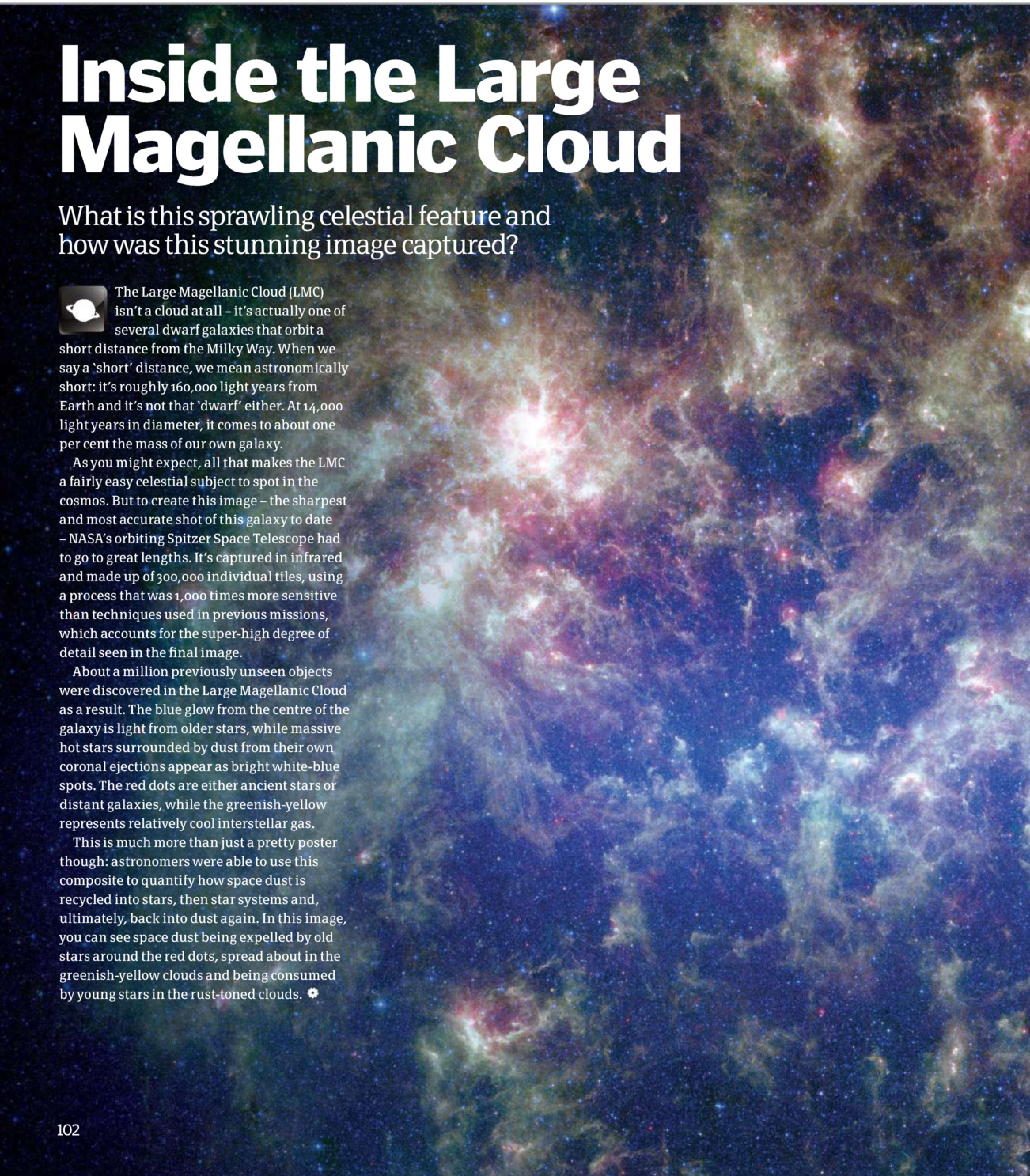
July 2012

Extrasolar comet storm
NASA's Spitzer Space Telescope finds evidence of a comet shower around the star Eta Corvi, 60 light years away.

1.5mn years from now

Future bombardment?
In 1.5 million years or so, a rogue star like Gliese 710 could send comets hurtling into the Solar System once more from the Oort Cloud.

© SPL; NASA; ESA



Inside the Large Magellanic Cloud

What is this sprawling celestial feature and how was this stunning image captured?

The Large Magellanic Cloud (LMC) isn't a cloud at all – it's actually one of several dwarf galaxies that orbit a short distance from the Milky Way. When we say a 'short' distance, we mean astronomically short: it's roughly 160,000 light years from Earth and it's not that 'dwarf' either. At 14,000 light years in diameter, it comes to about one per cent the mass of our own galaxy.

As you might expect, all that makes the LMC a fairly easy celestial subject to spot in the cosmos. But to create this image – the sharpest and most accurate shot of this galaxy to date – NASA's orbiting Spitzer Space Telescope had to go to great lengths. It's captured in infrared and made up of 300,000 individual tiles, using a process that was 1,000 times more sensitive than techniques used in previous missions, which accounts for the super-high degree of detail seen in the final image.

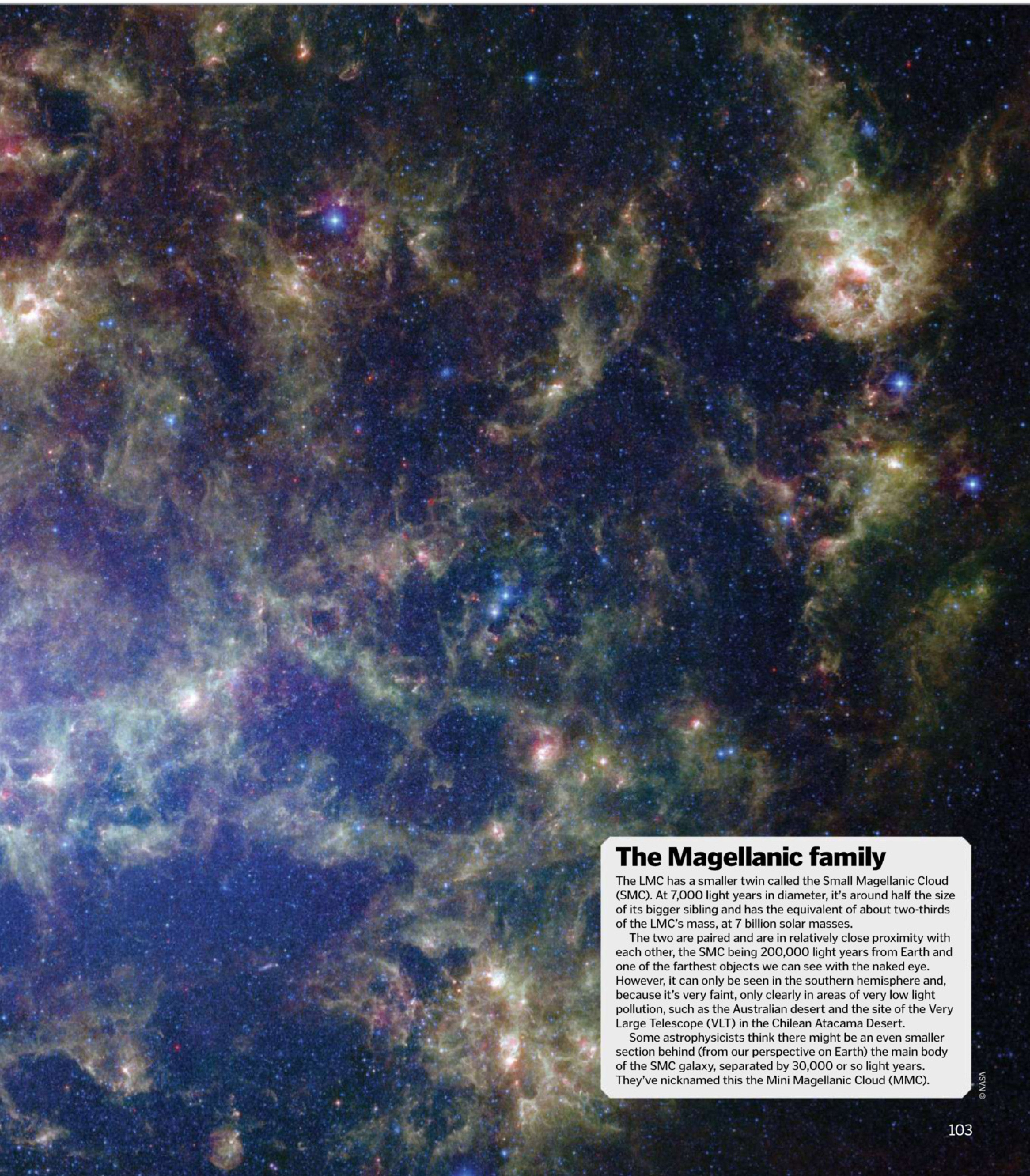
About a million previously unseen objects were discovered in the Large Magellanic Cloud as a result. The blue glow from the centre of the galaxy is light from older stars, while massive hot stars surrounded by dust from their own coronal ejections appear as bright white-blue spots. The red dots are either ancient stars or distant galaxies, while the greenish-yellow represents relatively cool interstellar gas.

This is much more than just a pretty poster though: astronomers were able to use this composite to quantify how space dust is recycled into stars, then star systems and, ultimately, back into dust again. In this image, you can see space dust being expelled by old stars around the red dots, spread about in the greenish-yellow clouds and being consumed by young stars in the rust-toned clouds. ✹

THE STATS
LMC IN NUMBERS

SOLAR MASSES	10bn
DISTANCE FROM EARTH	160,000LY
PLANETARY NEBULAS	400
YEAR FIRST RECORDED	964
SPITZER LAUNCH DATE	25/8/2003
MASS OF SPITZER	950kg

DID YOU KNOW? *If the whole of the LMC could be seen from Earth, it would cover as much sky as 480 full Moons*



© NASA

The Magellanic family

The LMC has a smaller twin called the Small Magellanic Cloud (SMC). At 7,000 light years in diameter, it's around half the size of its bigger sibling and has the equivalent of about two-thirds of the LMC's mass, at 7 billion solar masses.

The two are paired and are in relatively close proximity with each other, the SMC being 200,000 light years from Earth and one of the farthest objects we can see with the naked eye. However, it can only be seen in the southern hemisphere and, because it's very faint, only clearly in areas of very low light pollution, such as the Australian desert and the site of the Very Large Telescope (VLT) in the Chilean Atacama Desert.

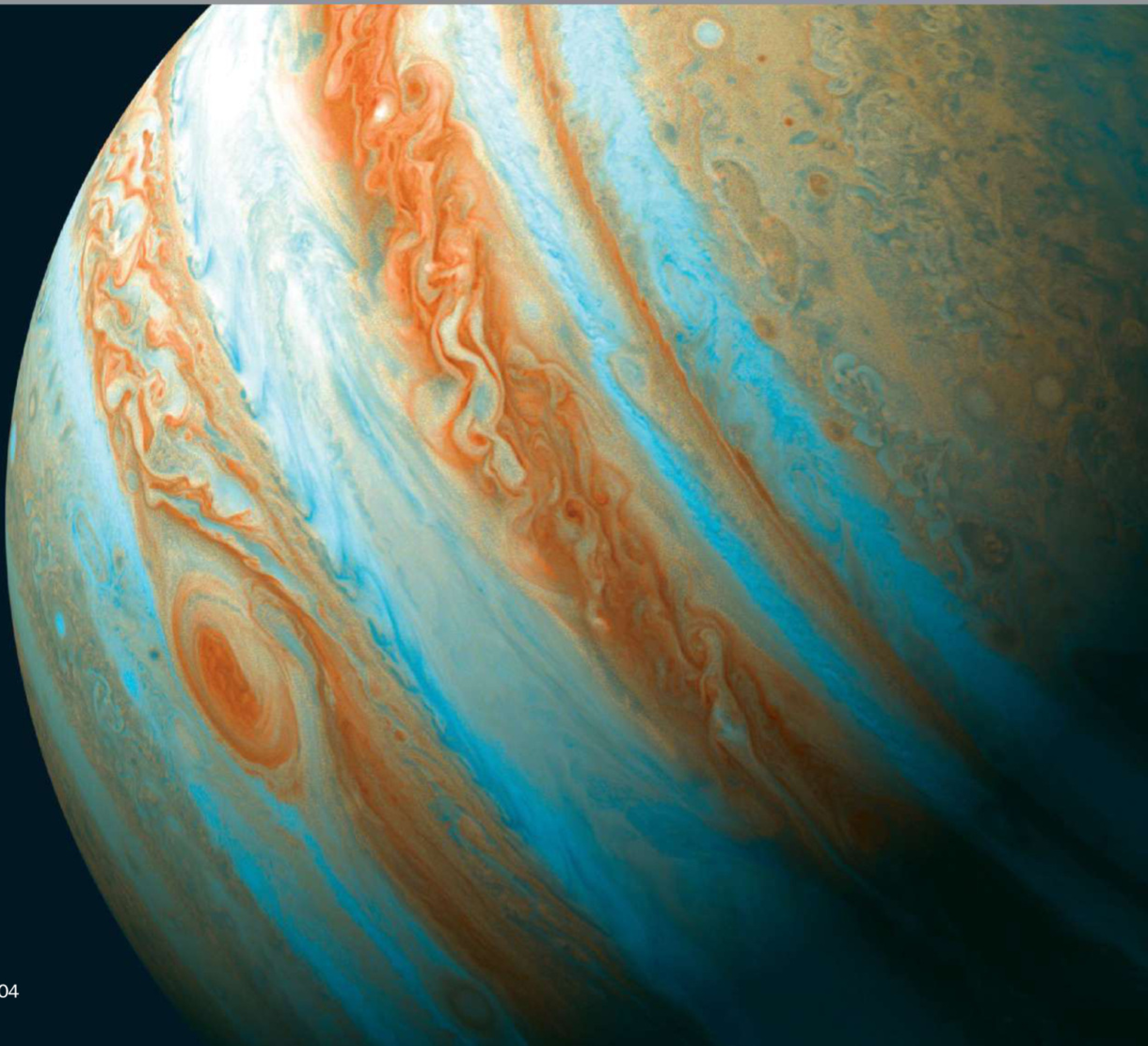
Some astrophysicists think there might be an even smaller section behind (from our perspective on Earth) the main body of the SMC galaxy, separated by 30,000 or so light years. They've nicknamed this the Mini Magellanic Cloud (MMC).

Wildest weather in space

We complain about the weather here on Earth, but weather on other planets is on a whole other scale of extremes

Weather on Earth can be extreme, but whatever's happening outside right now where you are, it's a safe bet that it's better than the weather in the rest of the Solar System.

Earth has the nicest weather thanks to a number of features: its size, its distance from the Sun, its axial tilt, orbital and rotational period, and its chemical composition. Although Earth's



RECORD BREAKERS
STORMY SATURN

2,000km

LARGEST STORM ON SATURN

In April 2013, the Cassini spacecraft imaged a storm on Saturn unlike anything seen before. At 2,000km (1,240mi) across, it could cover the UK over 12 times and had winds up to 530km/h (330mph).

DID YOU KNOW? *In 1989, geomagnetic storms caused an electrical blackout in Québec, Canada, that lasted 12 hours*

meteorology can be devastating, in comparison to some of our planetary neighbours, it's actually rather mild. Plus, a lot of our weather can be summed up in one word: water (albeit in various forms). Meanwhile, on planets lacking water, an atmosphere or a magnetic field to shield them from the worst of the Sun's radiation, you have to wonder why we're so keen to visit any of them!

One factor all of the planets have in common is the Sun and its emissions. The heliosphere is considered a part of the Sun's atmosphere, but it extends beyond Pluto, about 19 billion kilometres (12 billion miles) from the star.

So Earth does have some weather in common with other planets. In February 2014, researchers at NASA's Goddard Space Flight Center discovered a phenomenon that is common and rather pedestrian on Earth has much greater repercussions on Venus. A type of solar wind called a hot flow anomaly (HFA) causes massive explosions of energy, but on Earth it's deflected by the magnetosphere. However, Venus has no magnetosphere, so the explosions can cover the entire planet. Not that it was particularly hospitable anyway.

That's not even the strangest weather in the Solar System. While studying it can be difficult, our history of flybys, missions and probes are helping us to create detailed models of climate on other planets like Mars. Learning about similar effects on other planets – even in their more extreme form – is helping us better predict and prepare for changes in weather on Earth.

Jupiter's Great Red Spot

One of the defining features of the Solar System's biggest planet is a storm located about 22 degrees south of the equator in the South Equatorial Belt (SEB), commonly known as the Great Red Spot (GRS). Astoundingly, the GRS has been raging for more than 400 years, and is located at a higher altitude and measures colder than the surrounding cloud layer. It rotates anticlockwise, making one full rotation every six Earth days and is currently as large as two Earths across. The storm has shrunk by half its size in the past 100 years – at one point its diameter was measured at more than 40,000 kilometres (24,855 miles).

The GRS is different from storms on Earth because the heat generated within the planet continually replenishes it. Hurricanes on Earth dissipate when they make landfall, but Jupiter is gaseous, so the storm rages on. Jupiter's atmosphere is composed of cloud belts that rotate due to a system of jet streams. The northern side of the storm is bordered by an eastward jet stream and the southern side by a westward jet stream. These hold the storm in place as it makes laps around the planet.

Despite the high winds around it, there's little wind inside the storm. Its colour is probably caused by sulphuric compounds and varies from white to dark red, and sometimes it isn't visible at all. These colour changes seem to correspond to colour changes in the SEB, but without any predictable schedule.

Has lasted over 4,700x longer than Earth's longest storm

Dust storms can drastically raise the temperature, as the particles trap heat in Mars's atmosphere

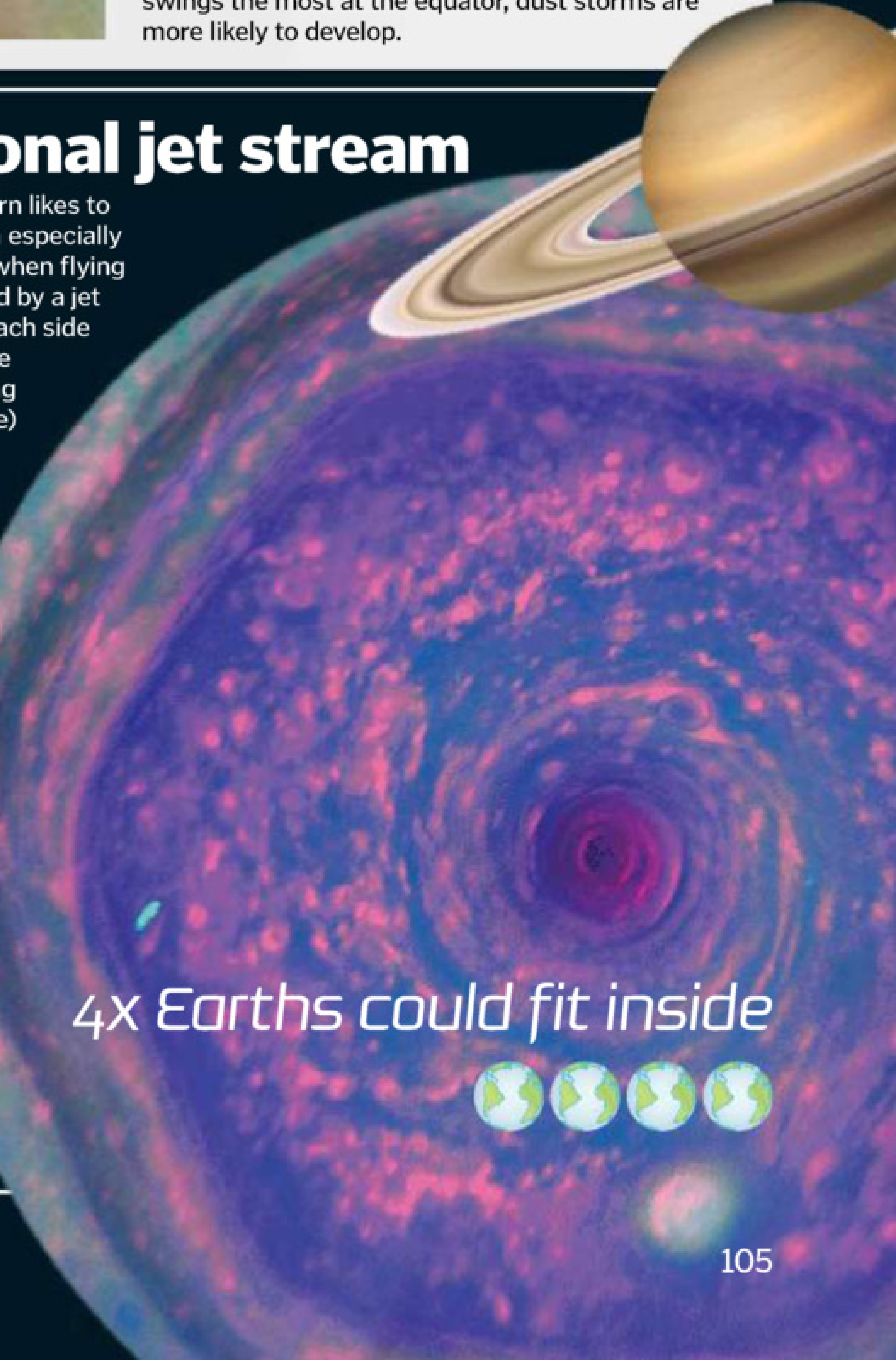
Dust storms on Mars

Earth's deserts have nothing on the Martian landscape when it comes to dust storms. The Red Planet is so dry, dusty and rocky that its dust storms can last for weeks. These storms develop quickly and can cover vast regions of the planet. Because the Martian atmosphere is so thin, superfine particles of dust rise in the air as heat from the Sun warms the atmosphere. Mars has such an eccentric orbit that its seasons are extreme; temperatures can be as low as -143 degrees Celsius (-225.4 degrees Fahrenheit) and as high as 35 degrees Celsius (95 degrees Fahrenheit). During Martian summers, when the temperature swings the most at the equator, dust storms are more likely to develop.

Saturn's hexagonal jet stream

Jet streams are generally circular, but Saturn likes to be different. The Voyager mission made an especially interesting discovery in the early-Eighties when flying over the planet's north pole. It's surrounded by a jet stream that's not circular but hexagonal. Each side of this immense hexagon is estimated to be around 15,000 kilometres (9,321 miles) long and it has a 30,000-kilometre (18,640-mile) diameter. It surrounds a vortex and rotates at the same rate as Saturn (a day on Saturn is about ten and a half hours).

In order to explain this unusual feature, University of Oxford physicists re-created it in a laboratory. They used a cylinder of water to serve as the planet's atmosphere with a ring inside it to represent the jet stream (with green dye to make it visible). The cylinder was placed on a spinning table and the ring spun faster than the water. The faster the ring spun, the less circular the jet stream became. By varying the speed and the differences between the rotations of the water and the ring, different shapes appeared. So the theory is that the rate at which this particular jet stream spins in relation to the Saturnian atmosphere is what leads to the odd hexagonal cloud formation.

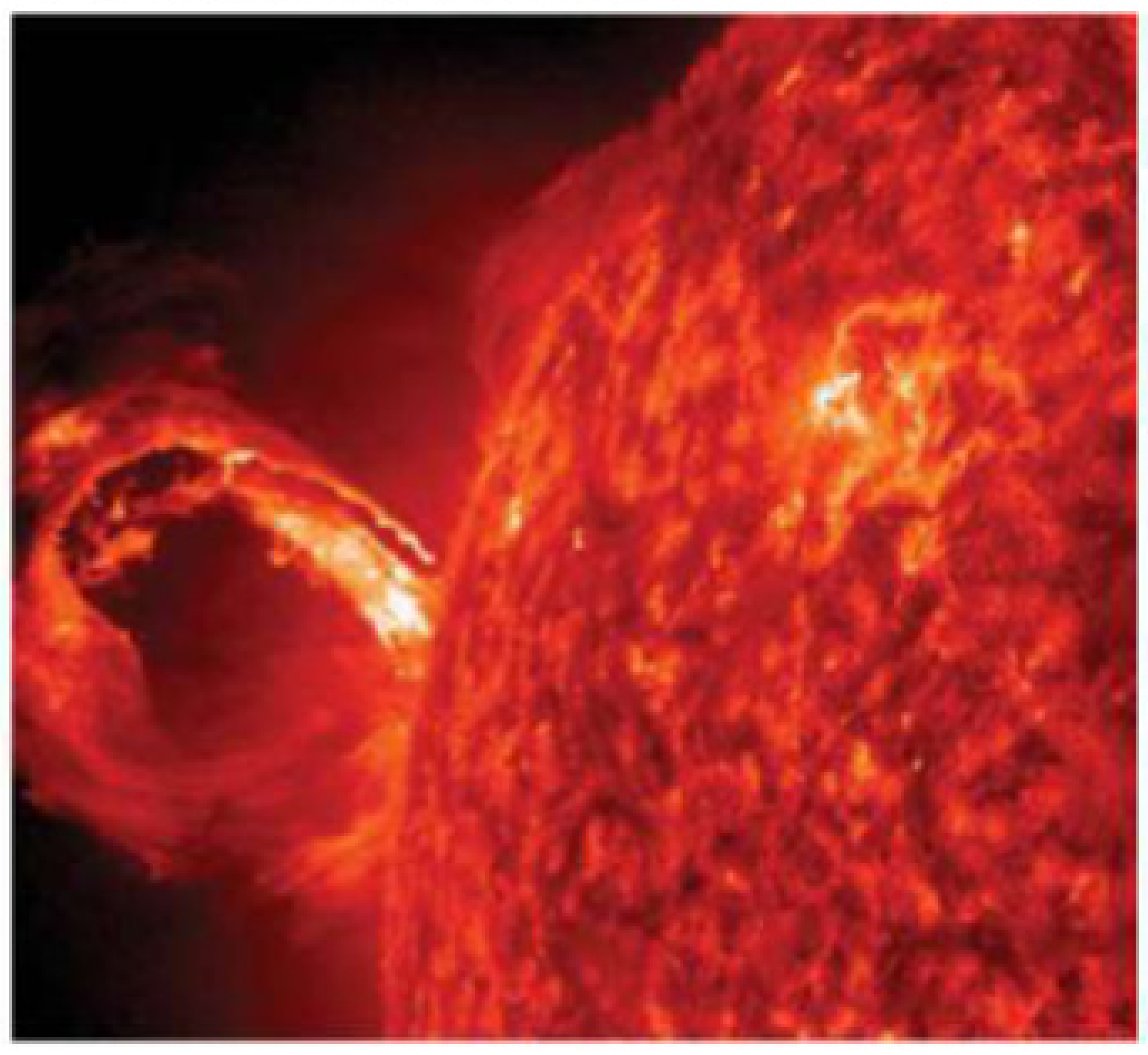


What role does the Sun play in space weather?

There are numerous factors that affect weather on each planet in the Solar System, but they all have one thing in common: the Sun. Two main types of solar activity take place in the Sun's atmosphere that have far-reaching effects. Coronal mass ejections (CMEs) and solar flares can wreak havoc on a planet. CMEs are bursts of magnetic fields and solar winds that release matter and electromagnetic radiation. Solar flares are massive bursts of light and energy that release atoms, ions, electrons and radiation. A CME usually follows a solar flare.

These energy surges from the Sun can result in solar energetic particles (SEPs), highly energised particles including electrons, ions and protons that can travel as fast as 80 per cent the speed of light. SEPs and other matter and radiation that reach Earth cause geomagnetic storms that can have a variety of effects.

They cause the stunning polar auroras, but other effects are less desirable. In the case of solar flares, there's an increase in the amount of UV radiation in the Earth's atmosphere, which can affect the movement and longevity of satellites by making the atmosphere denser. They can cause interference and disruption of communications and navigation on the surface, while particles from flares can damage delicate electronics on satellites or the International Space Station. They can even cause changes in the Earth's climate.



You can find out whether it rains any other gems in space in Brain Dump on page 84

Saturn's diamond rain

Some researchers believe that lightning storms on Saturn could result in diamond precipitation – as much as 1,000 tons each year. The theory is that lightning zapping the methane in the atmosphere releases carbon atoms from the gas. These carbon atoms stick together and drift down towards the planet's core. As the pressure and temperature mount, the carbon is compressed into graphite and eventually diamonds that could be as big as a centimetre (0.4 inches) in diameter.

However, when the diamonds reach the core – where temperatures can be as hot as 7,727 degrees Celsius (13,940 degrees Fahrenheit) – the gemstones would melt into a liquid state.

Violent Neptunian winds

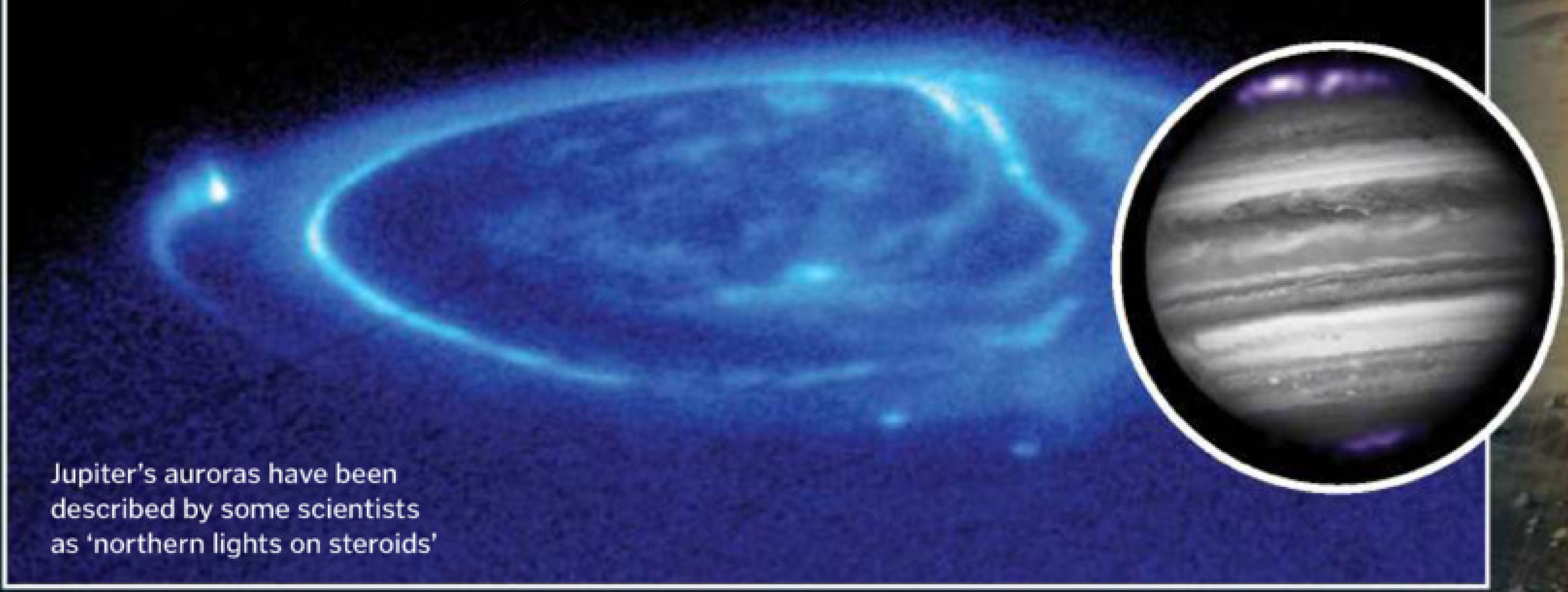
The outermost planet in our Solar System has some seriously extreme weather in general, but what really blows astronomers away is its wind. In fact, Neptune is home to the strongest gales anywhere in the Solar System, topping out at over 2,100 kilometres (1,300 miles) per hour – about the speed of a fighter jet. By comparison, winds on Earth generally max out at 400 kilometres (250 miles) per hour. These powerful winds move in a direction opposite from the rotation of the planet. There are two different theories for what causes these winds. One idea is that although they're very powerful, these winds remain high up in the atmosphere, in a layer no more than 1,000 kilometres (600 miles) thick. This means that the processes causing these winds are also shallow, likely due to the condensation and evaporation of moisture in the atmosphere. The other theory is that these processes are much lower in the atmosphere, caused by the meeting of the heat generated from within the planet as its core shrinks as it meets the extreme cold at the surface (below -200 degrees Celsius/-328 degrees Fahrenheit). If the winds do prevail deeper into the atmosphere, they may also be so intense because the planet's featureless surface contains nothing to slow them down.

5x stronger than gusts on Earth

☁☁☁☁☁

Jupiter's electric auroras

The auroras on Earth get a lot of attention for their beauty, but Jupiter has auroras larger than the entire Earth. In fact, they produce nearly a million megawatts of energy! And unlike Earth-based auroras, they're always happening. On Earth, the light displays are caused by solar storms, but Jupiter's auroras are self-generated. As the planet rotates, it generates electricity at its poles and forces charged particles (ions) into the atmosphere, which causes a reaction that results in beautiful light displays. One potential source for the ions is Jupiter's moon Io, but scientists aren't quite sure how this happens. Ultraviolet images of the auroras reveal not just their blue glow, but also three blobs of light. These are Galilean moons Io, Ganymede and Europa as they interact with Jupiter's magnetic field.



Jupiter's auroras have been described by some scientists as 'northern lights on steroids'

STRANGE BUT TRUE
RAIN, RAIN, GO AWAY

What would happen if you stood on Venus and it rained?

A You'd melt B You'd smell funny C Nothing

Answer:
Although rain on Venus is corrosive sulphuric acid, the surface heat is so intense (480°C/900°F) that the rain evaporates before reaching it. Of course, acid would be the last of your worries with that intense heat and a surface pressure 90 times greater than Earth's!

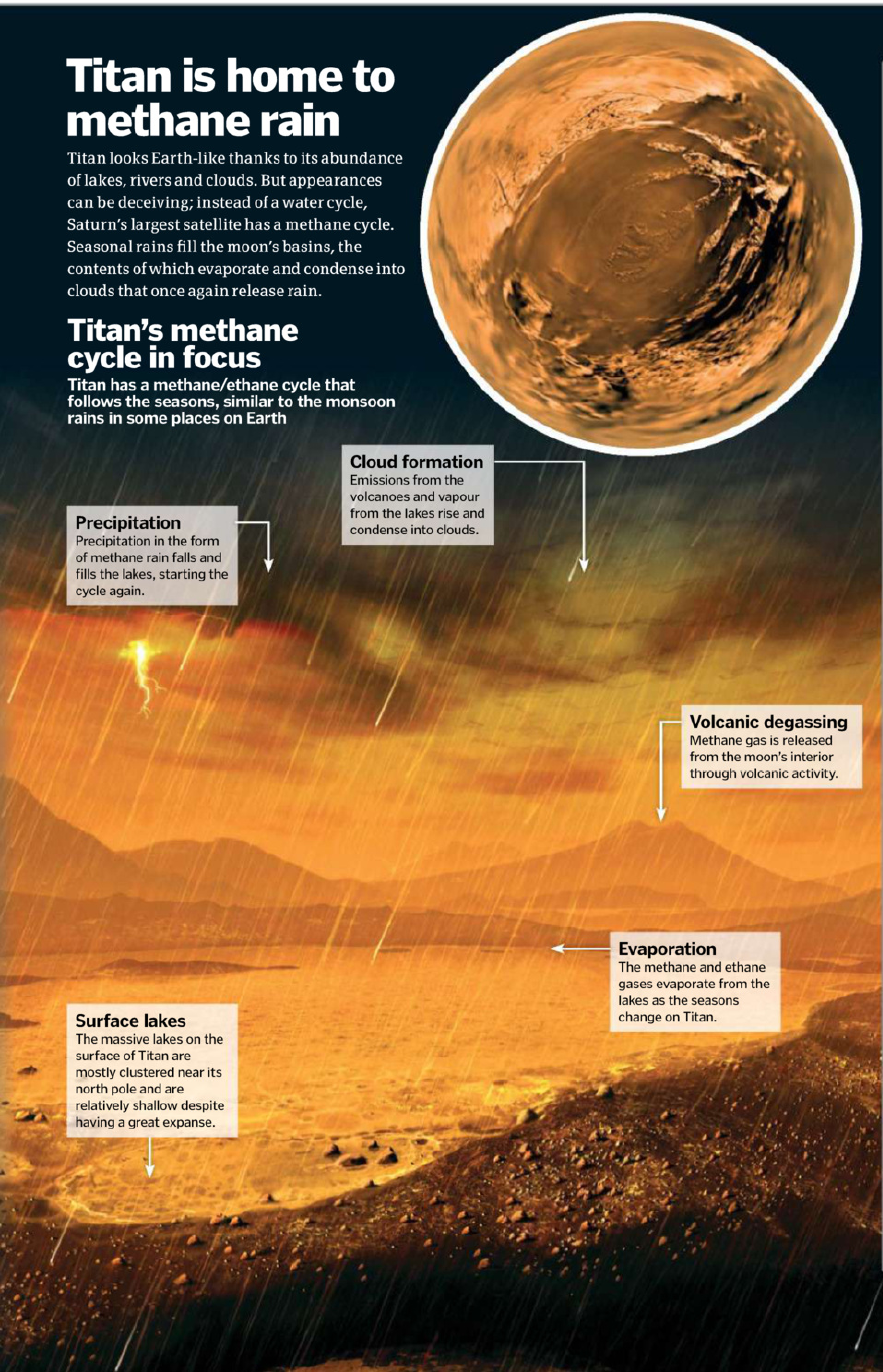
DID YOU KNOW? *Solar flares can release energy equivalent to the explosion of millions of 100-megaton hydrogen bombs*

Titan is home to methane rain

Titan looks Earth-like thanks to its abundance of lakes, rivers and clouds. But appearances can be deceiving; instead of a water cycle, Saturn's largest satellite has a methane cycle. Seasonal rains fill the moon's basins, the contents of which evaporate and condense into clouds that once again release rain.

Titan's methane cycle in focus

Titan has a methane/ethane cycle that follows the seasons, similar to the monsoon rains in some places on Earth



Cloud formation
Emissions from the volcanoes and vapour from the lakes rise and condense into clouds.

Precipitation
Precipitation in the form of methane rain falls and fills the lakes, starting the cycle again.

Volcanic degassing
Methane gas is released from the moon's interior through volcanic activity.

Evaporation
The methane and ethane gases evaporate from the lakes as the seasons change on Titan.

Surface lakes
The massive lakes on the surface of Titan are mostly clustered near its north pole and are relatively shallow despite having a great expanse.

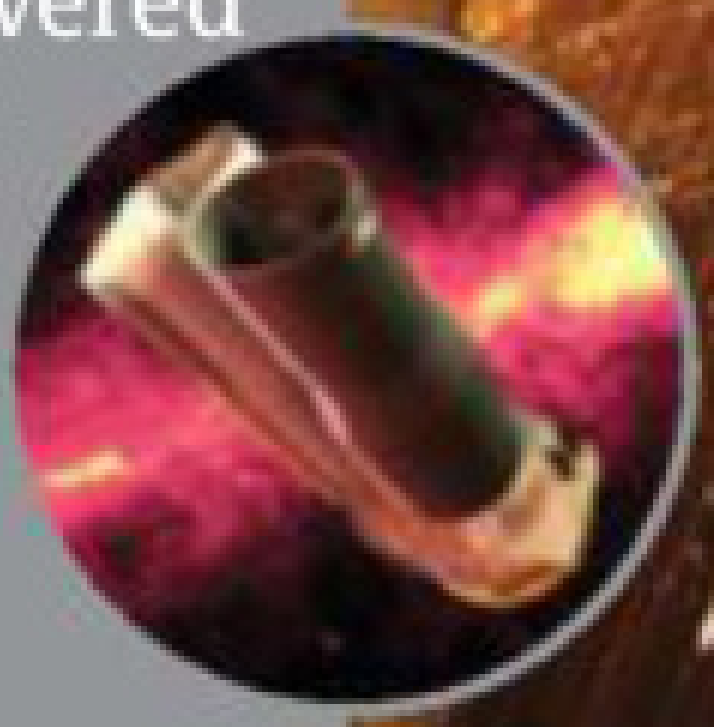
Top 5 weather satellites

GPM – Launch: 2014
The Global Precipitation Measurement will provide 4D views of hurricanes, rainstorms and even falling snow on Earth. It will be used for both long-term climate research and provide live weather forecasts.

DSCOVR – Launch: 2015
The Deep Space Climate Observatory satellite will spot space weather (like solar flares) that could be damaging to Earth. DSCOVR will be in an orbit 1.5mn km (932,000mi) away to escape some of the Earth's magnetic effects.

SOHO – Launch: 1995
The Solar and Heliospheric Observatory mission is in a halo orbit around the Earth. SOHO was commissioned to study the Sun, but it has also discovered more than 2,000 comets.

CASSIOPE – Launch: 2013
The Cascade Smallsat and Ionospheric Polar Explorer is a small satellite specifically designed to gather data on solar storms that affect the Earth's upper atmosphere and cause auroras as well as magnetic interference.



SST – Launch: 2003
The Spitzer Space Telescope observatory is unusual because it has a heliocentric orbit, slowly drifting away from Earth. In its extensive studies of stars, the SST has discovered space weather on some of the smallest stars around, known as brown dwarfs.

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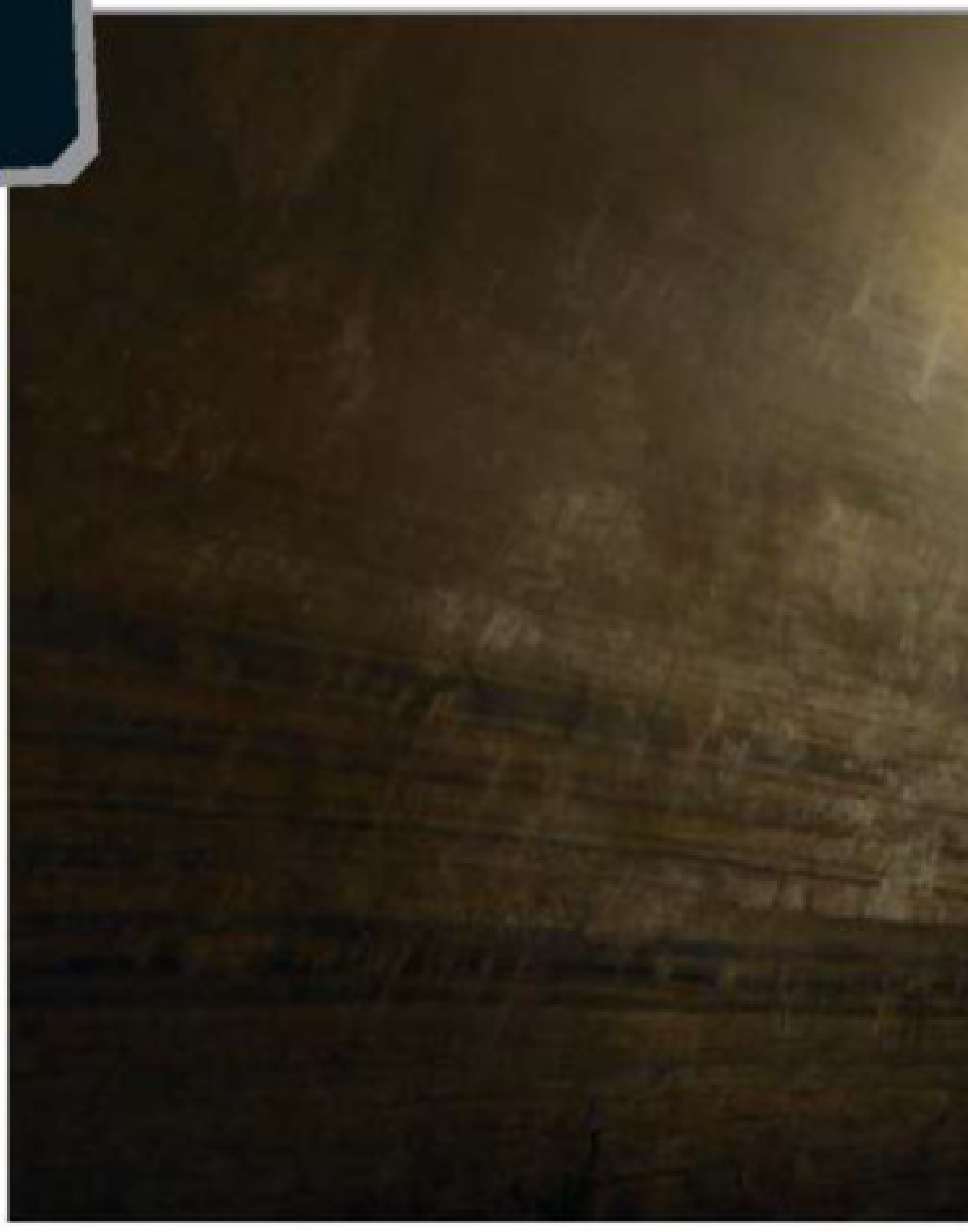
HOW IT WORKS

SCIENCE OF WEATHER

The causes and effects of our weather



112 The carbon cycle What happens to the air that we breathe?

114 How the Arctic ocean freezes What causes the oceans to freeze?

116 Mammatus clouds How do they warn us of incoming tornadoes?

116 How is dew formed? How does this appear on the ground?

117 What are Von Kármán vortices? The science behind the mind-boggling cloud formations

118 How do waterfalls freeze? How does the moving water freeze?

119 Why do we get red sky at night? What causes shepherds delight in the sky?

119 What is wind-chill factor? How does it feel colder than it actually is?

119 The smell of rain What causes rain to have its own smell?

120 Cave weather How do caves have their very own microclimate?

122 The ozone layer explained What exactly is it that we are destroying?

123 Why are clouds white? What makes the clouds above our heads appear white?

123 Rain shadows How do these cause deserts to form on one side of a mountain

124 How the seasons work What makes winter different to summer?

126 How, and why, does it rain? What causes water to fall from the sky?

126 What are fog, mist and haze? What is the difference between these three similar weathers?

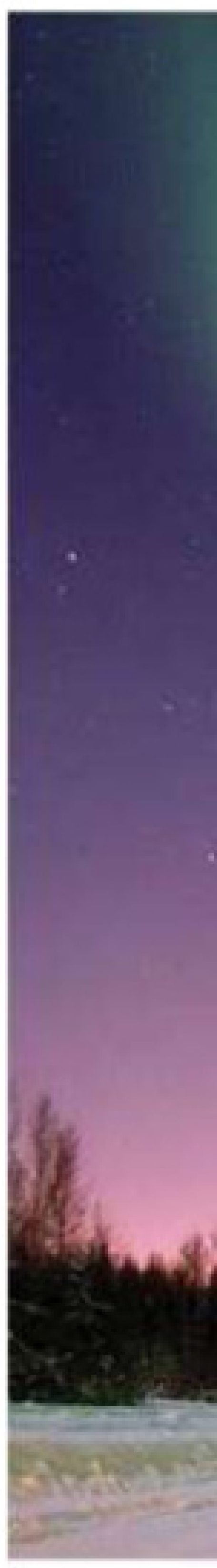
127 Double rainbows What causes the secordary rainbow that we see?

128 Why is snow white? Why does snow appear to be white?

129 What are lenticular clouds? Explore how cloud formations can end up looking like UFOs

129 Aurora borealis The reasons behind the beautiful night sky lights explored

130 Nitrogen cycle What is in the air that we breathe?

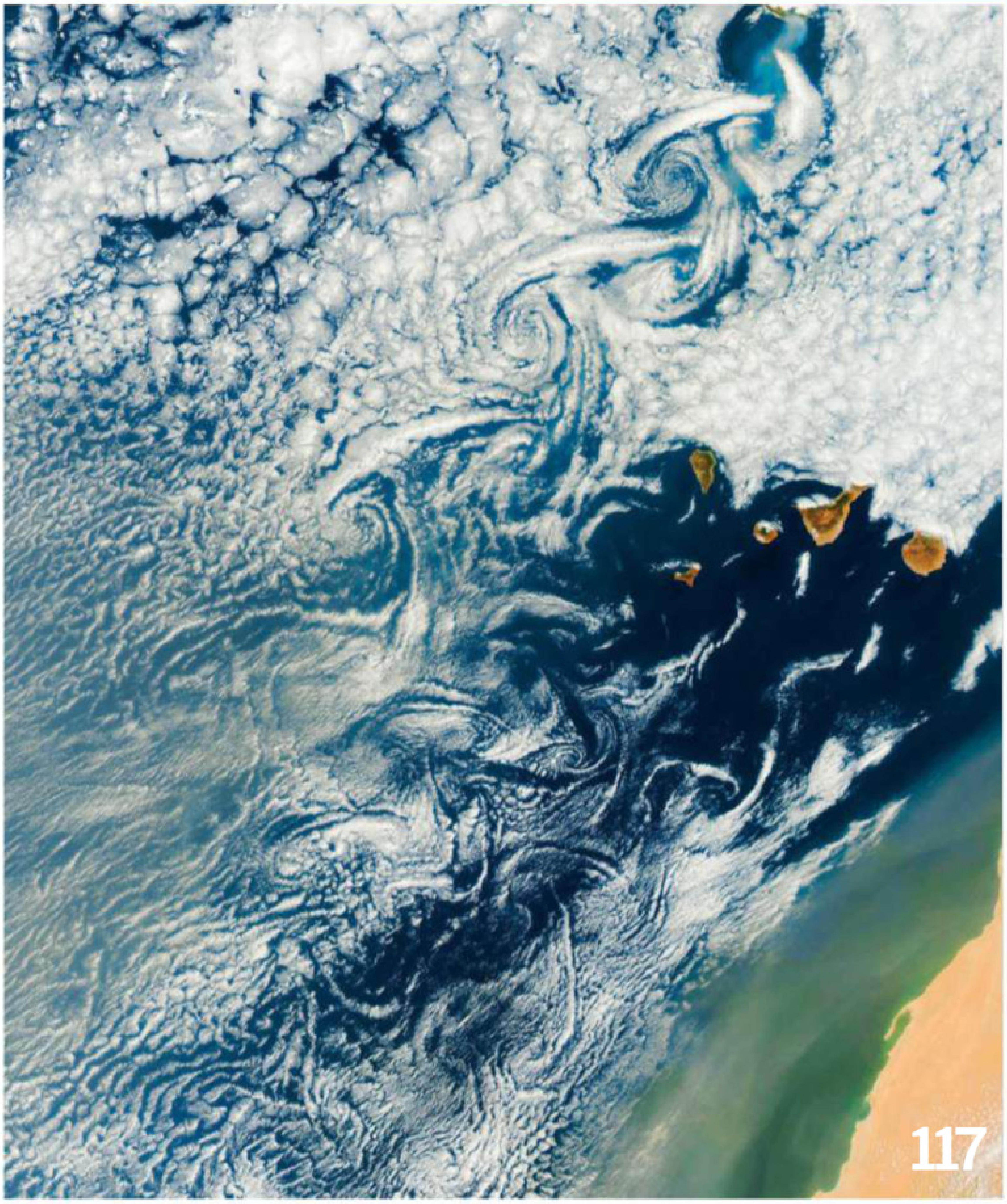


SCIENCE OF WEATHER

132 **Influencing cloud formation**
What makes the clouds the various shapes?

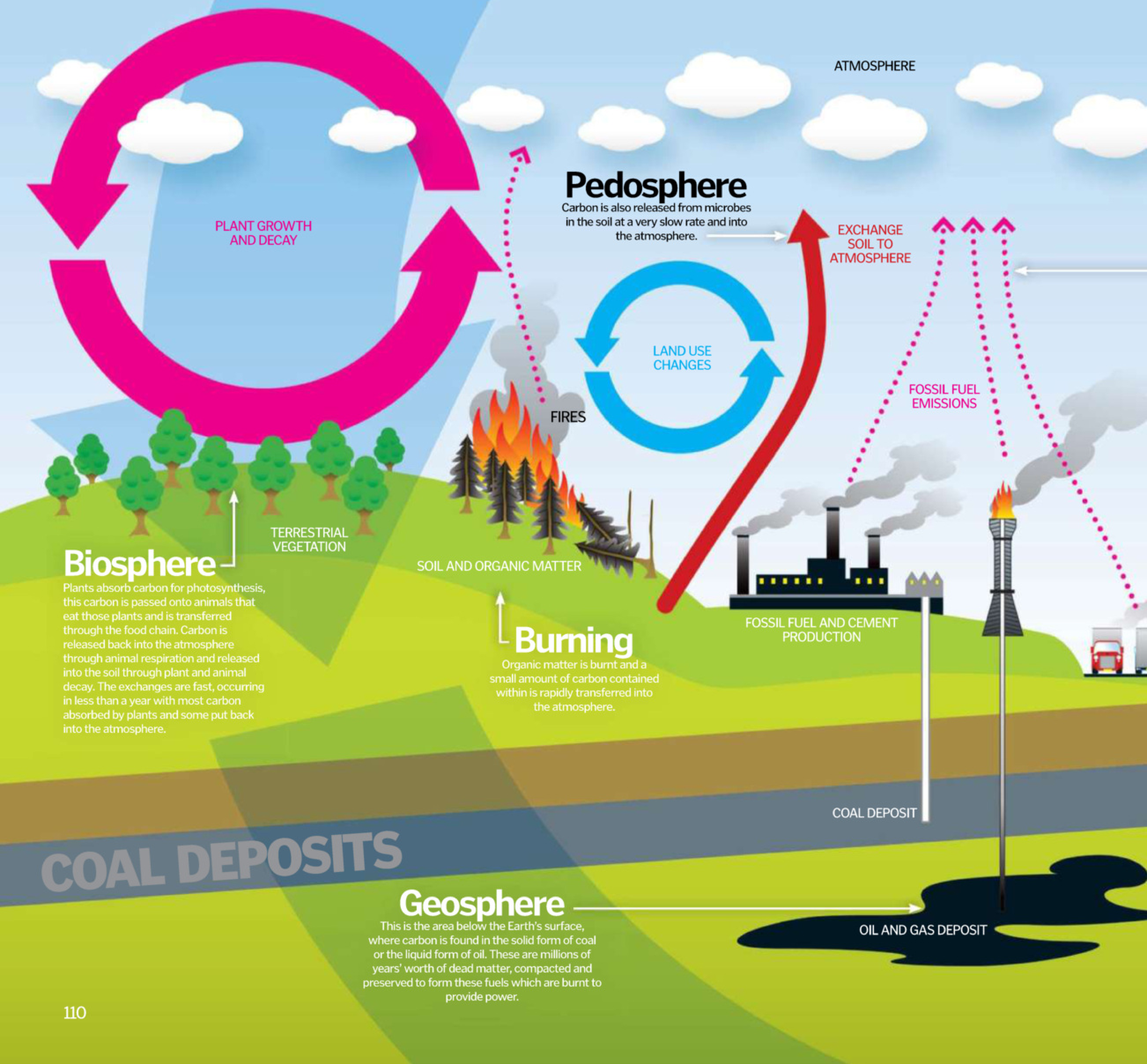
133 **Snowflakes**
How are snowflakes formed into the most intricate shapes?

133 **Weather symbols**
Explore the different symbols used by forecasters



The carbon cycle

You're breathing it out right now, but where's it been before and where's it off to?



Pedosphere

Carbon is also released from microbes in the soil at a very slow rate and into the atmosphere.

Biosphere

Plants absorb carbon for photosynthesis, this carbon is passed onto animals that eat those plants and is transferred through the food chain. Carbon is released back into the atmosphere through animal respiration and released into the soil through plant and animal decay. The exchanges are fast, occurring in less than a year with most carbon absorbed by plants and some put back into the atmosphere.

Burning

Organic matter is burnt and a small amount of carbon contained within is rapidly transferred into the atmosphere.

Geosphere

This is the area below the Earth's surface, where carbon is found in the solid form of coal or the liquid form of oil. These are millions of years' worth of dead matter, compacted and preserved to form these fuels which are burnt to provide power.

5 TOP FACTS
USES OF CARBON

Dry ice

1 Dry ice is solid carbon dioxide. It is frozen carbon dioxide with a temperature of -78.5°C and melts into a gaseous rather than liquid form to create the popular smoke effect.

Fizzy drinks

2 When held under pressure carbon dioxide dissolves in water, and it then causes bubbles on your tongue as it forms a carbonic acid as you take a gulp.

Carbon dating

3 The age of fossils and minerals can be found by using carbon-14 which is a radioactive isotope of carbon. It has been used to date the age of dinosaur bones.

Teeth whitening

4 Carbon is a key element involved in teeth whitening treatments, found as carbon amide peroxide in both dentist and over-the-counter treatments.

Fire extinguishers

5 A fire extinguisher containing carbon dioxide is mainly used for fighting electrical fires. The carbon goes back into the atmosphere without leaving any harmful fumes.

DID YOU KNOW? *The carbon within you now will probably have been used in the ocean and helped a plant photosynthesise*

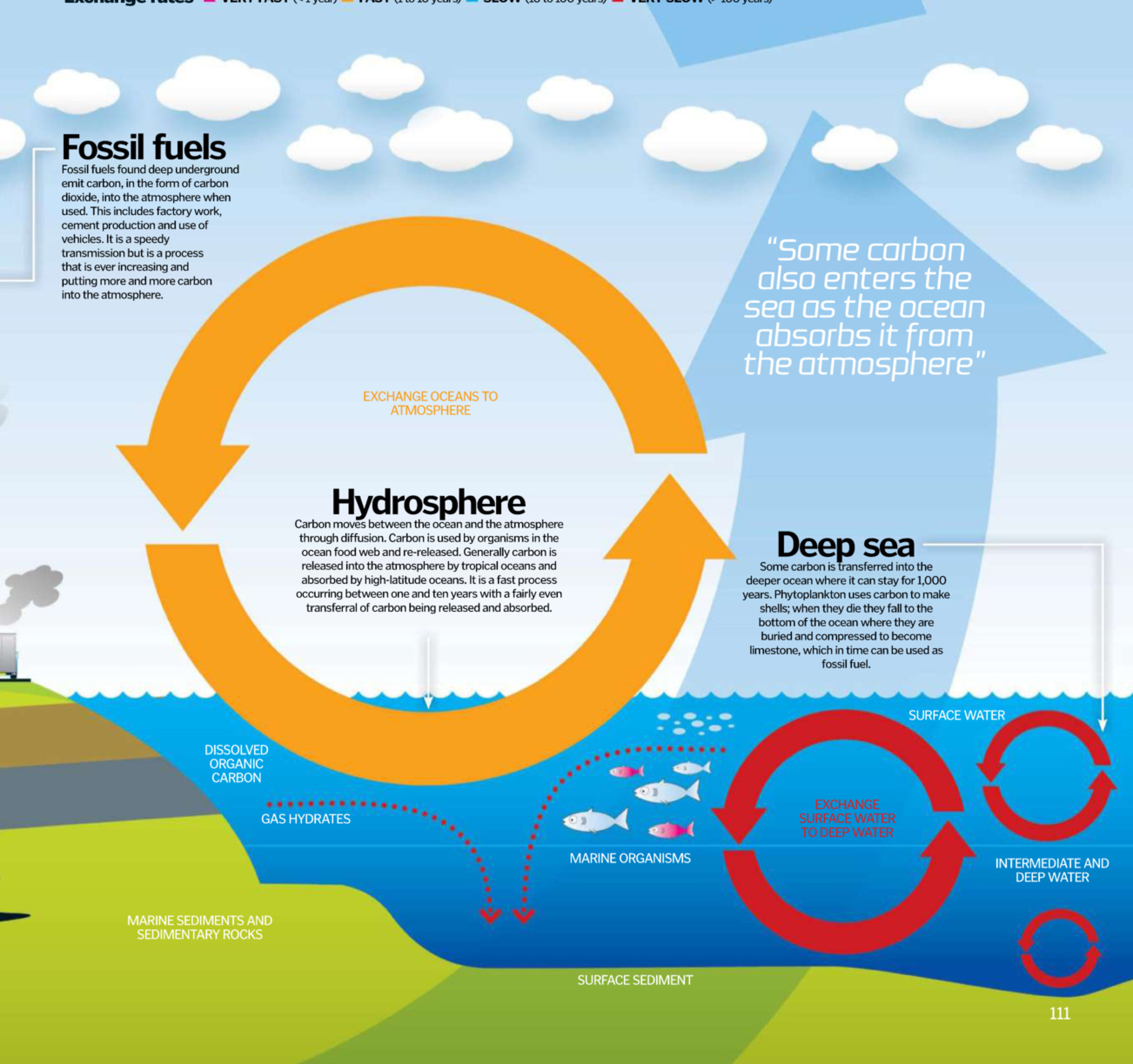
Carbon is a greenhouse gas that helps trap heat and keep the Earth warm. Just as water is transferred around the Earth, carbon atoms also follow a cycle and are used again and again. You might not be able to see carbon but it is a vital part of how our world works and it moves around the Earth in a variety of ways.

Carbon moves from the atmosphere into plants. In the atmosphere it is combined with oxygen and found as carbon dioxide. Plant photosynthesis draws the carbon out of the air to make plant food. The carbon then moves from plants into animals as animals eat the plants. The carbon moves up the food chain as each animal is eaten by another. Animals release carbon back into the atmosphere through respiration when they breathe out CO_2.

When plants and animals die the carbon is transferred into the soil when decomposition occurs. Some of this carbon will end up buried miles underground and so will eventually make fossil fuels. These fossil fuels are then burned and used for power, in the form of factories, cars and so on, therefore releasing the carbon back into the atmosphere. Some carbon also enters the sea as the ocean absorbs it from the atmosphere.

Although the carbon cycle is a natural process it can be affected by human activity; our burning of fossil fuels means there is 30 per cent more carbon dioxide in the air now than 150 years ago.

Exchange rates 🟪 **VERY FAST** (< 1 year) 🟧 **FAST** (1 to 10 years) 🟦 **SLOW** (10 to 100 years) 🟥 **VERY SLOW** (> 100 years)


EXCHANGE OCEANS TO ATMOSPHERE
DISSOLVED ORGANIC CARBON
GAS HYDRATES
MARINE ORGANISMS
SURFACE WATER
EXCHANGE SURFACE WATER TO DEEP WATER
INTERMEDIATE AND DEEP WATER
MARINE SEDIMENTS AND SEDIMENTARY ROCKS
SURFACE SEDIMENT

Fossil fuels

Fossil fuels found deep underground emit carbon, in the form of carbon dioxide, into the atmosphere when used. This includes factory work, cement production and use of vehicles. It is a speedy transmission but is a process that is ever increasing and putting more and more carbon into the atmosphere.

> "Some carbon also enters the sea as the ocean absorbs it from the atmosphere"

Hydrosphere

Carbon moves between the ocean and the atmosphere through diffusion. Carbon is used by organisms in the ocean food web and re-released. Generally carbon is released into the atmosphere by tropical oceans and absorbed by high-latitude oceans. It is a fast process occurring between one and ten years with a fairly even transferral of carbon being released and absorbed.

Deep sea

Some carbon is transferred into the deeper ocean where it can stay for 1,000 years. Phytoplankton uses carbon to make shells; when they die they fall to the bottom of the ocean where they are buried and compressed to become limestone, which in time can be used as fossil fuel.

Why are there holes in the ozone layer?

The creation and destruction of ozone in Earth's atmosphere explained

Held in place by gravity, Earth's atmosphere is a thick protective shield that extends 400 kilometres (270 miles) out from the planet's surface. In the lower stratosphere – at a height of between 15 and 50 kilometres (9 and 30 miles) – is a layer of ozone (O_3), which is a colourless but highly reactive gas. This 'ozone layer', which varies in concentration, provides a natural sunscreen for Earth against the Sun's potentially harmful ultraviolet (UV) radiation. While UV does have a positive effect on the body – it stimulates the production of vitamin D – overexposure damages skin cells. So the depletion of this protective gaseous layer has very serious implications for life on Earth.

Every spring high over Antarctica, and to a lesser extent in the Arctic, the ozone layer thins so that 'holes' appear. As a result there is less protection against UV radiation, and geoscientists are monitoring this closely.

While a normal oxygen molecule (O_2) consists of two oxygen atoms, ozone (O_3) has three. Most of the ozone in the stratosphere is created when powerful solar photons break the bonds inside O_2 molecules, freeing individual oxygen atoms (O), which can then rejoin normal O_2 atoms to create O_3.

The main offenders in the depletion of ozone are chlorofluorocarbons (CFCs), which are now banned in many countries. These organic carbon, fluorine and chlorine compounds are produced by man-made substances like refrigerants and the propellant in aerosol cans. When released into the atmosphere these CFCs then accumulate in the stratosphere. Cold temperatures over Antarctica cause the formation of polar vortices, which create high-altitude ice clouds. When the Sun's light hits these clouds the CFCs convert into a highly reactive form of chlorine that destroys ozone.

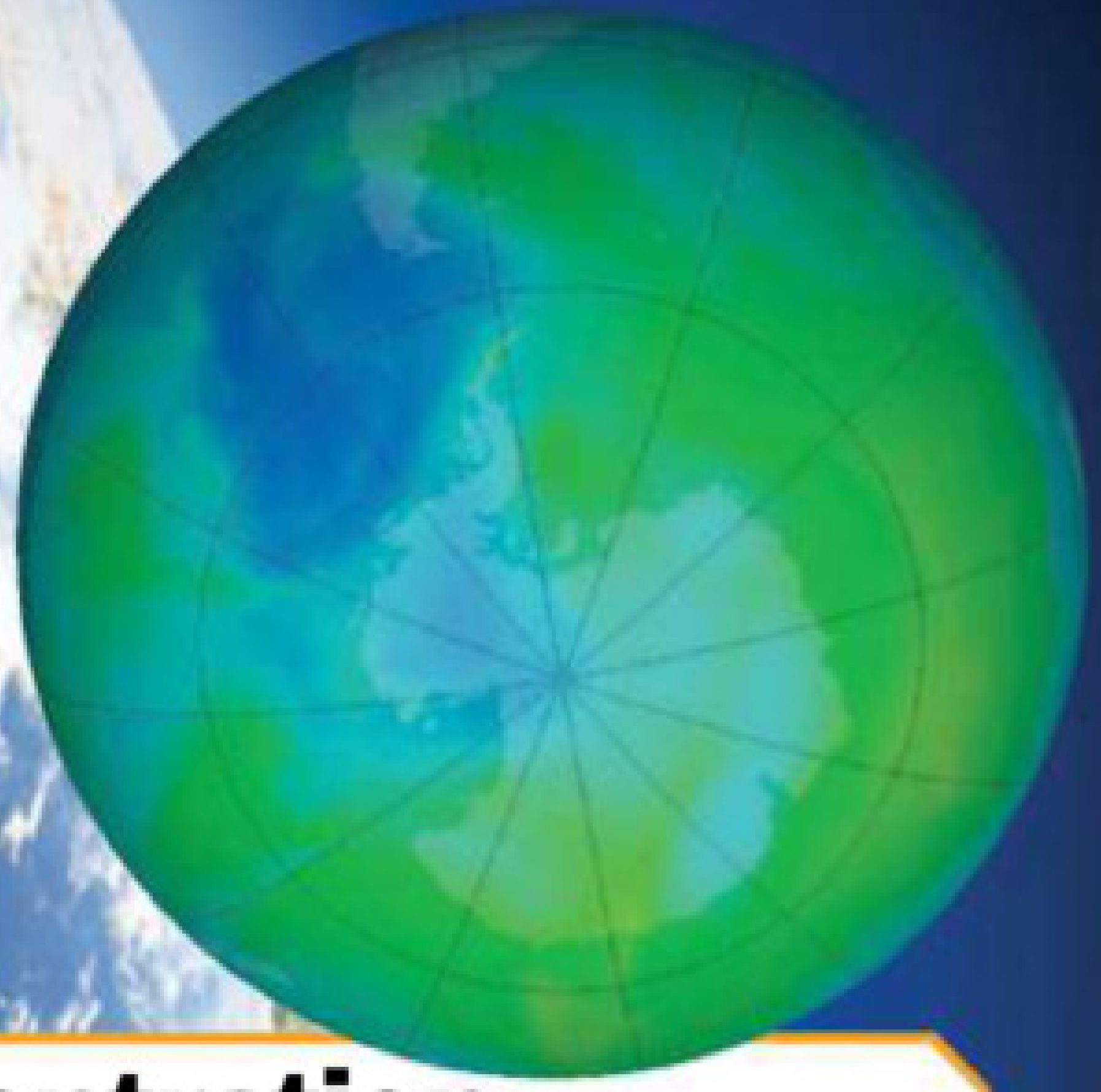
While the holes diminish in size during the warmer months, every spring the ozone layer in both the Antarctic and Arctic regions shrinks. CFC pollutants have been greatly reduced since their damage was discovered in the Seventies, but it will take a long time for the CFCs to completely deteriorate. ✱

Why is ozone so thin at the poles?

The presence of CFCs
There's a lot of chlorine and bromine in the stratosphere. 80 per cent of Antarctica's chlorine comes from CFCs.

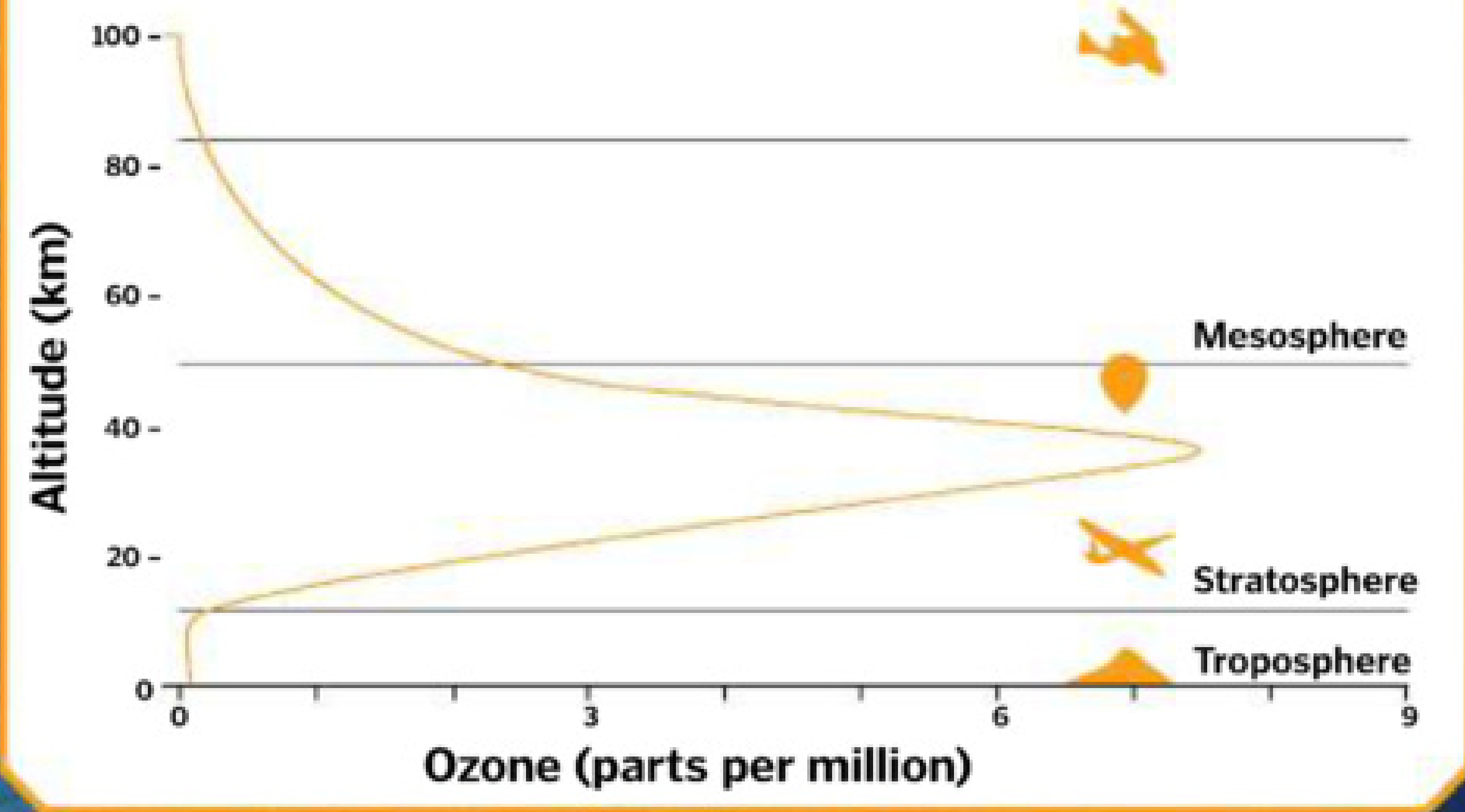
It's cold at the poles
The cold temperatures at Earth's polar extremes cause stratospheric polar clouds whose particles react chemically to release chlorine in a form that destroys ozone.

Sunlight is the catalyst
The energy from the Sun over Antarctica in August/September (ie spring) is a catalyst for a reaction that sees a single chlorine molecule destroy thousands of ozone molecules.



Ozone concentration

Take a look at how ozone is distributed through our planet's atmosphere



© NASA

DID YOU KNOW? *The biggest cloud is the cumulonimbus. They're dark and can contain millions of tons of water*

Atmospheric temperature

Why does the air temperature radically fluctuate with altitude?

We're taught hot air rises and we can see this in practice when a hot-air balloon climbs into the sky. So why does the air temperature plummet at greater altitudes? There are a number of variables that affect atmospheric temperature and the best known is solar radiation. This doesn't heat the air directly though. Lapse rate describes the general decrease in atmospheric temperature with height, which occurs because the atmosphere is heated by conduction with the Earth's surface. The farther you move from the surface, the less dense the air is and the more it struggles to retain heat. But the temperature doesn't follow a unidirectional gradient. For example, while at 80 kilometres (50 miles) it can be -100 degrees Celsius (-148 degrees Fahrenheit), the air is much warmer at 115 kilometres (70 miles) due to ionising radiation.

Atmosphere layer by layer

Take a trip through Earth's atmosphere to see the location of the hottest and coldest areas

1. Troposphere

This extends up to about 12km (7mi) and is where our weather occurs. Temperature drops about 6.5°C per kilometre here.

2. Stratosphere

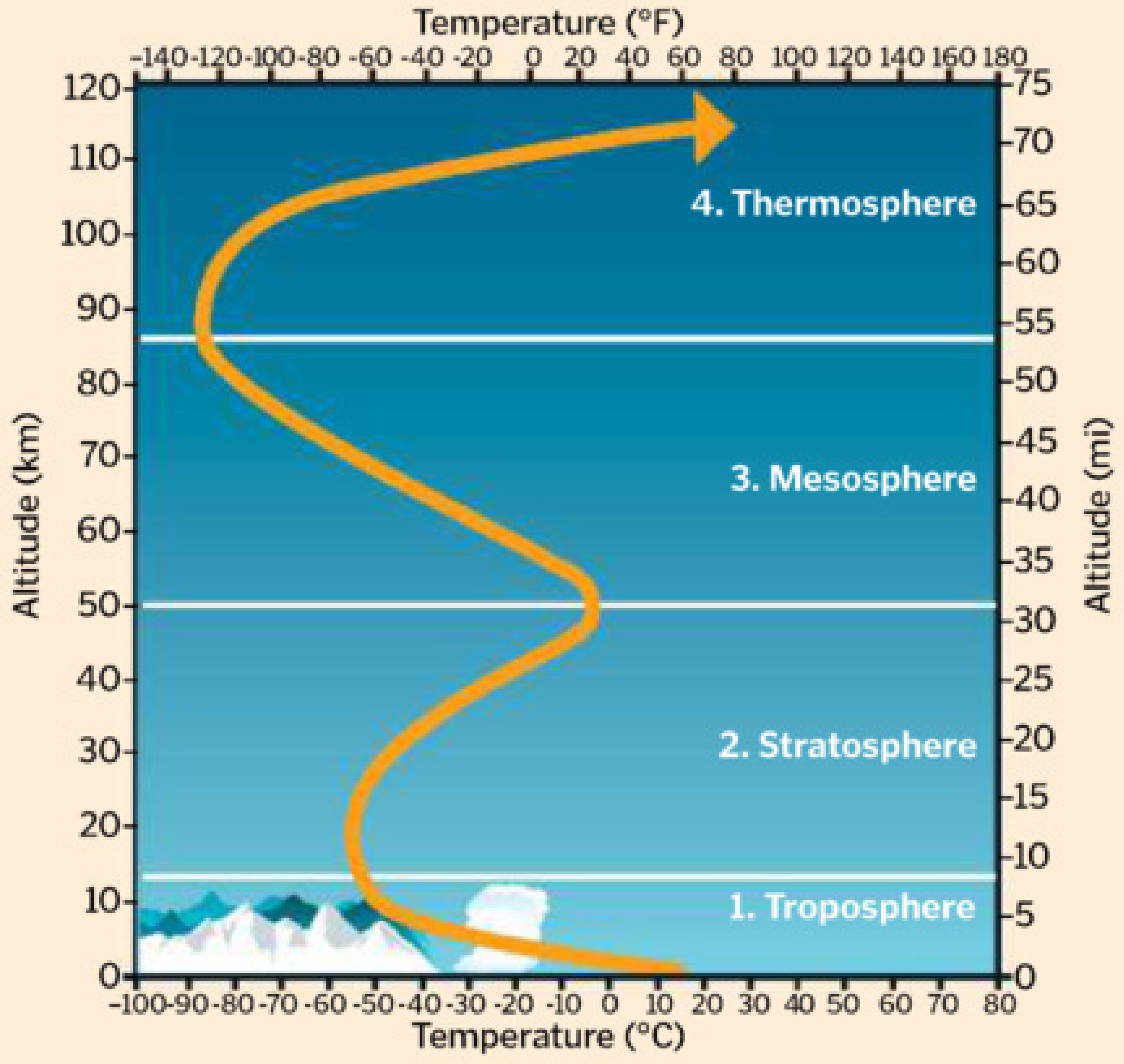
The bulk of the ozone layer is here and the temperature increases to just below freezing near the stratopause.

3. Mesosphere

Between 50km (31mi) and 100km (62mi) temperatures plummet because of CO_2 cooling and low solar heating.

4. Thermosphere

Stretching up to 600km (373mi) from the Earth's surface air here can reach 1,800°C (3,272°F) but is too thin for us to feel it.

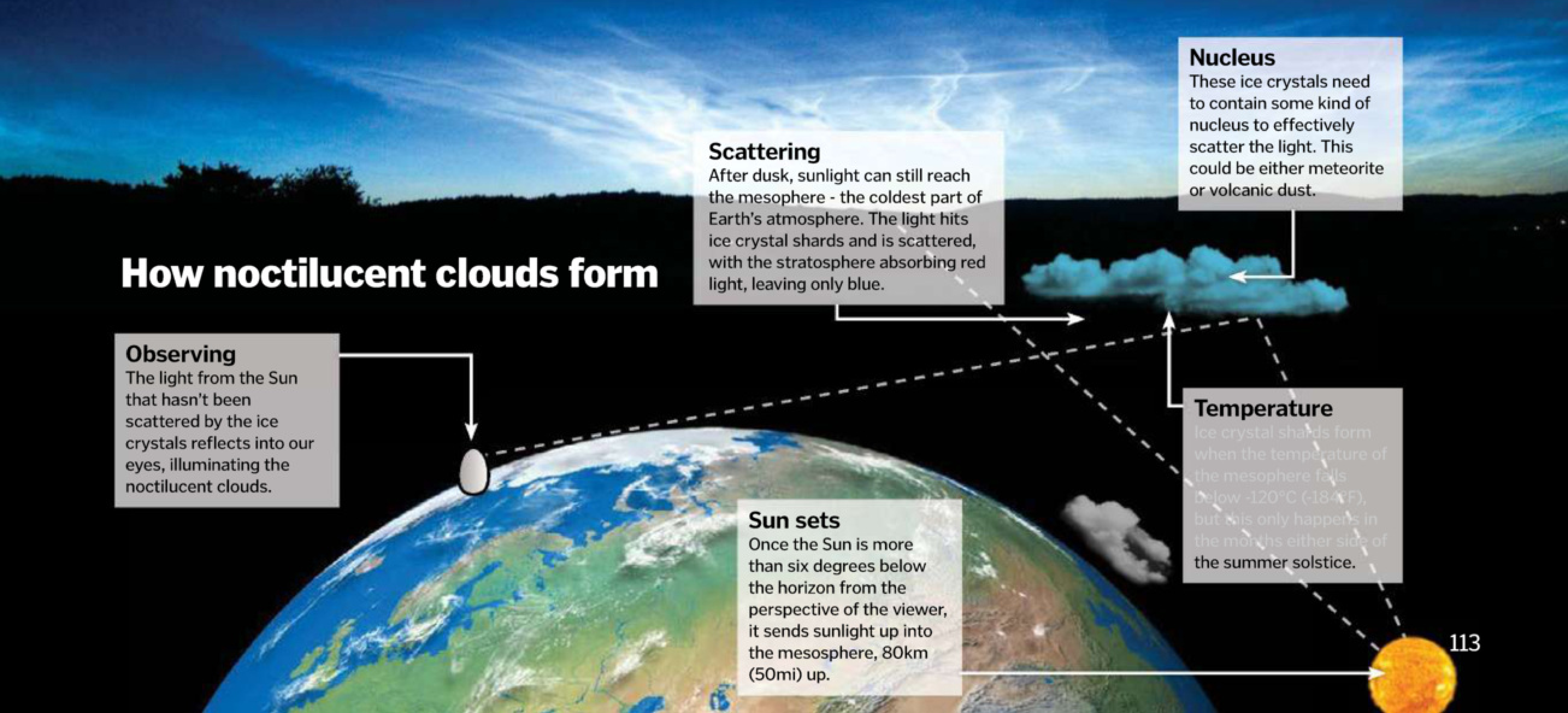


The different levels of the Earth's atmosphere

Clouds that shine at night

How do these glow-in-the-dark noctilucent clouds form high in the Earth's atmosphere?

How noctilucent clouds form



Scattering
After dusk, sunlight can still reach the mesophere - the coldest part of Earth's atmosphere. The light hits ice crystal shards and is scattered, with the stratosphere absorbing red light, leaving only blue.

Nucleus
These ice crystals need to contain some kind of nucleus to effectively scatter the light. This could be either meteorite or volcanic dust.

Observing
The light from the Sun that hasn't been scattered by the ice crystals reflects into our eyes, illuminating the noctilucent clouds.

Temperature
Ice crystal shards form when the temperature of the mesophere falls below -120°C (-184°F), but this only happens in the months either side of the summer solstice.

Sun sets
Once the Sun is more than six degrees below the horizon from the perspective of the viewer, it sends sunlight up into the mesosphere, 80km (50mi) up.

How the Arctic Ocean freezes

It's difficult to imagine such a huge expanse of water freezing solid, so how is it possible?

Arctic sea ice is that which forms on the Arctic Ocean during the winter months. Pure water, which contains no other molecules, substances or impurities, freezes at 0 degrees Celsius (32 degrees Fahrenheit). The world's seawater, on the other hand, contains around 3.5 per cent dissolved minerals and salts. This additional material lowers the freezing point of the seawater to around -2 degrees Celsius (28.4 degrees Fahrenheit) because the freezing point depends on the number of molecules present in a solution, as well as the type of molecule(s).

During the winter months, when the air temperature in the Arctic starts to fall dramatically, a deep layer of seawater begins to develop minuscule ice crystals; this slushy water is called frazil ice. A further drop in temperature causes the frazil ice to thicken. Pockets of salty slush accumulate until they become so heavy they start to sink. This leaves the top layer of icy crystals with significantly less salt content. The freezing point of this surface water therefore becomes higher and the falling temperatures enable the crystals to solidify into pack ice.

This pack ice grows to become one huge floating sheet (made up of many smaller floes), the thickness and coverage of which varies over the year, but reaches its peak in March. During the warmer summer months, meanwhile, the ice begins to retreat and break up, reaching its lowest extent around September.

THE STATS
ARCTIC TRIVIA

AREA BY WHICH ARCTIC SEA ICE IS RECEDING PER DECADE 10%
SEAS AROUND THE ARCTIC OCEAN 8
NUMBER OF NATIVE PEOPLES >30
POPULATION ~4 million
ANNUAL PRECIPITATION 50cm
COLDEST TEMP ON RECORD -68°C

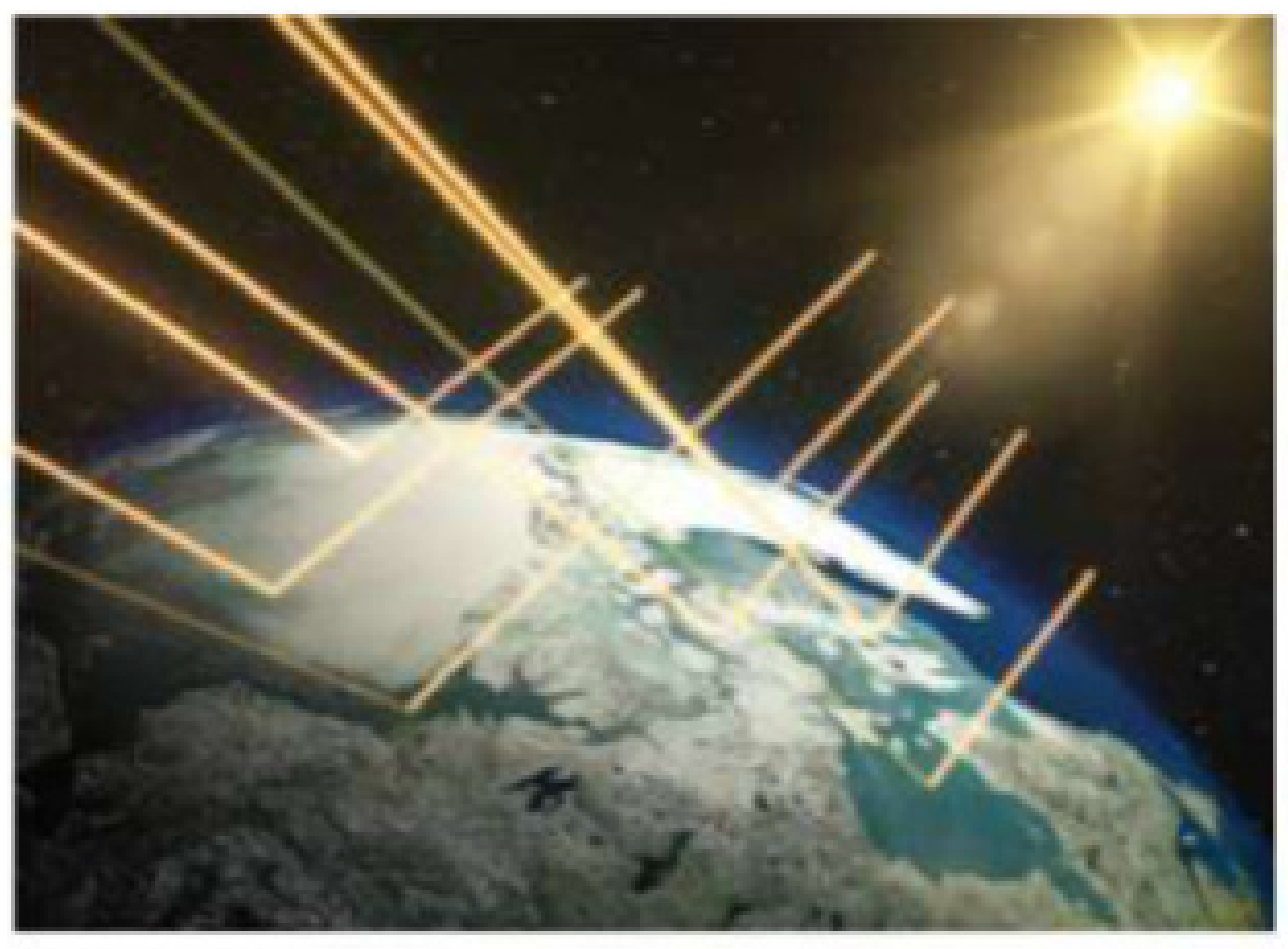
DID YOU KNOW? At its current rate of decline, it's predicted there will be no Arctic sea ice left by the end of the century

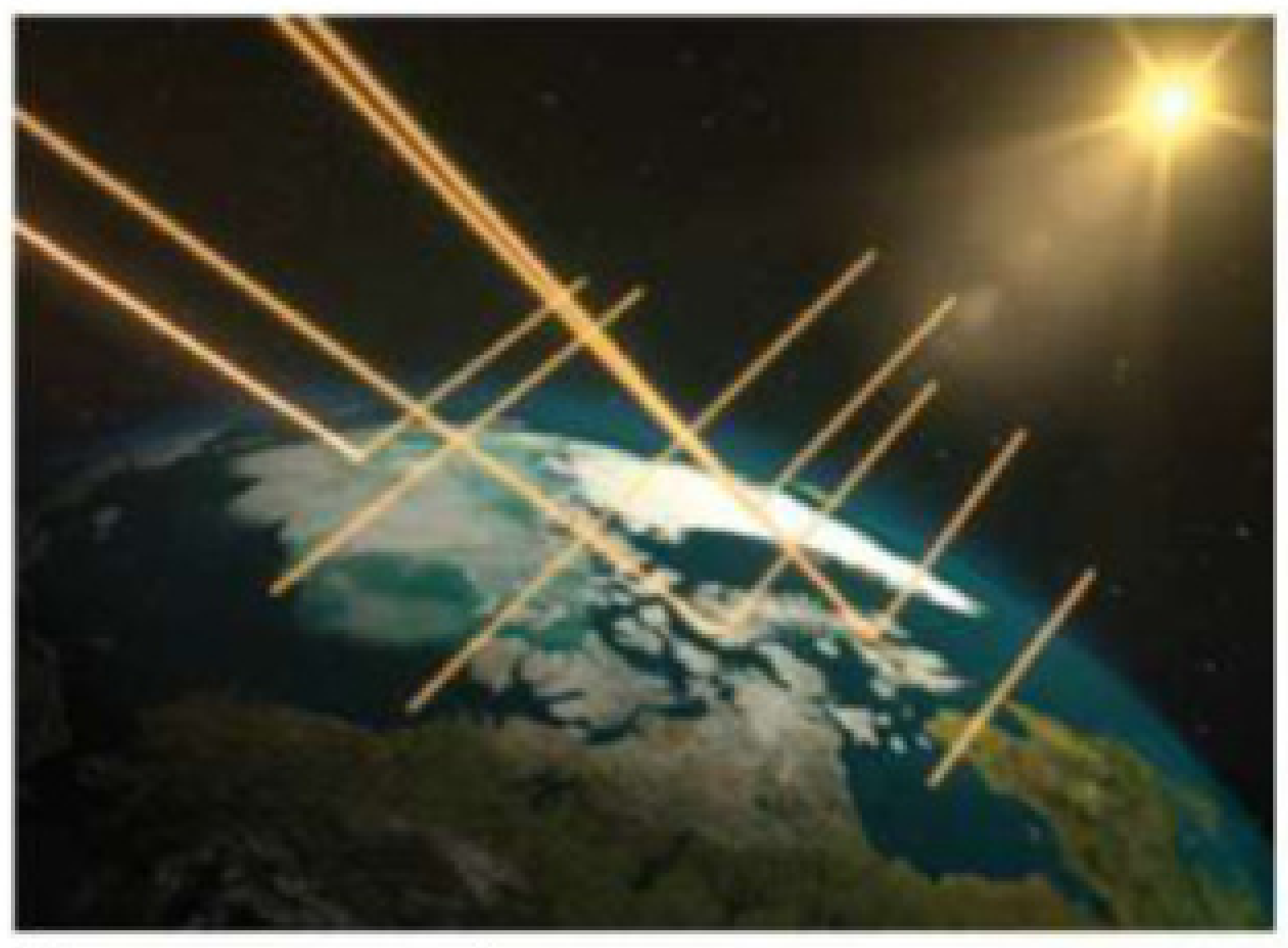
A satellite shot of sea ice floes and icebergs off the coast of Antarctica

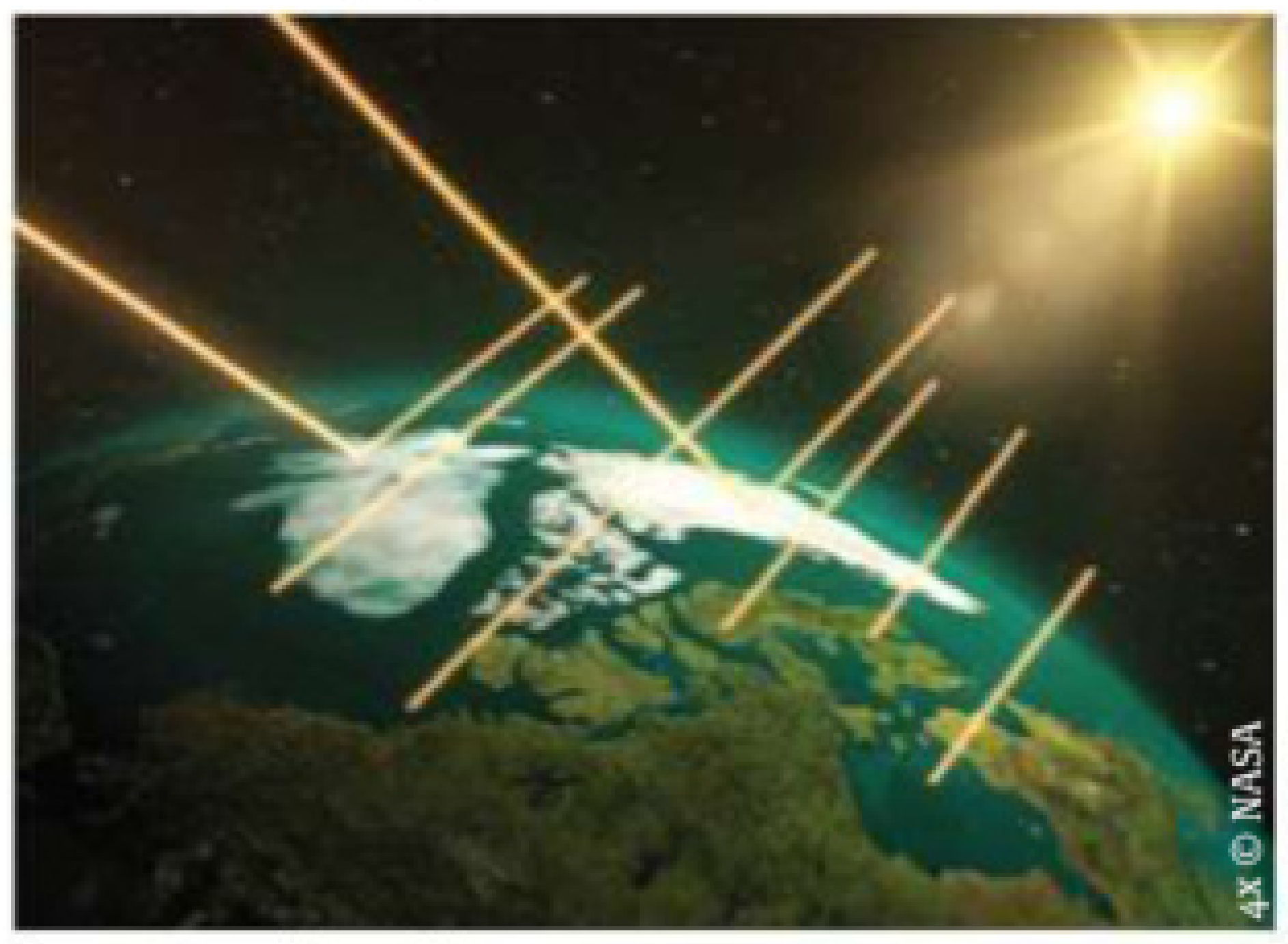
© SPL

How polar ice affects the world climate

Sea ice at the poles is important because it influences the weather across the entire planet. The ice acts like a mirror, deflecting the Sun's rays back into the atmosphere. As the ice melts, more of the 'dark' ocean beneath, capable of absorbing the Sun's heat, is exposed. When the Arctic is frozen, warmer water entering from the Pacific or Atlantic begins to cool, becoming dense and sinking. This displacement of water drives the circulation of Earth's oceans, affecting weather and conditions throughout the world. So, in many respects, the amount and extent of Arctic sea ice is critical to the global climate.


High reflection
The white sea ice cover acts like a mirror, reflecting the Sun's rays back out to space, preventing the sea from heating excessively.


Sea exposed
As the ice melts, there is more dark seawater to absorb sunlight, which further melts the ice.


4x © NASA

Low reflection
The more sunlight absorbed by the seawater, the more the ice melts until, eventually, significantly less light is reflected back into space.

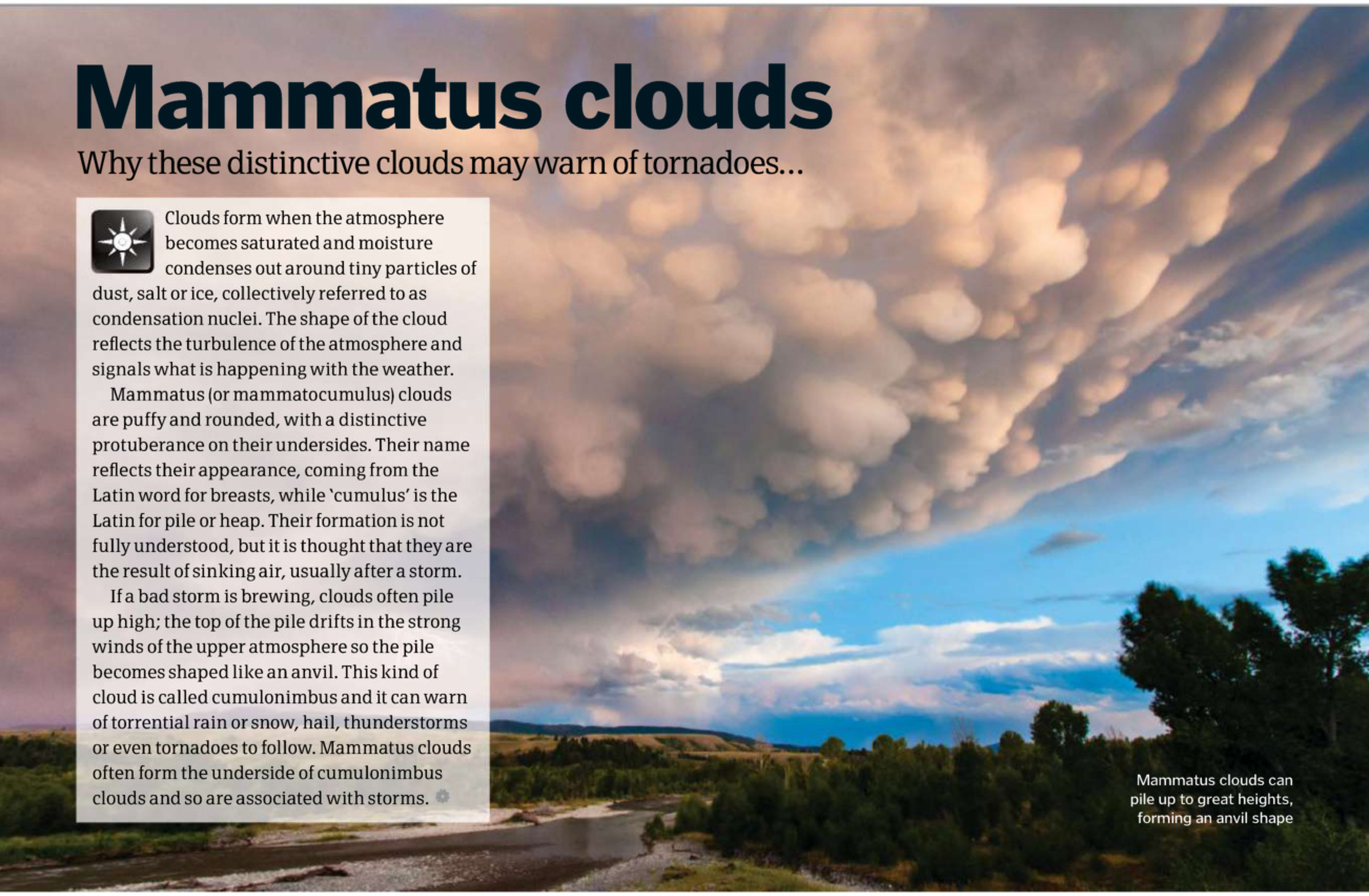
Mammatus clouds

Why these distinctive clouds may warn of tornadoes…

Clouds form when the atmosphere becomes saturated and moisture condenses out around tiny particles of dust, salt or ice, collectively referred to as condensation nuclei. The shape of the cloud reflects the turbulence of the atmosphere and signals what is happening with the weather.

Mammatus (or mammatocumulus) clouds are puffy and rounded, with a distinctive protuberance on their undersides. Their name reflects their appearance, coming from the Latin word for breasts, while 'cumulus' is the Latin for pile or heap. Their formation is not fully understood, but it is thought that they are the result of sinking air, usually after a storm.

If a bad storm is brewing, clouds often pile up high; the top of the pile drifts in the strong winds of the upper atmosphere so the pile becomes shaped like an anvil. This kind of cloud is called cumulonimbus and it can warn of torrential rain or snow, hail, thunderstorms or even tornadoes to follow. Mammatus clouds often form the underside of cumulonimbus clouds and so are associated with storms.



Mammatus clouds can pile up to great heights, forming an anvil shape

How is dew formed?

Discover why these sparkling drops appear on the ground

Glinting dewdrops are a familiar sight for early risers in the morning, but dew is not a sign of overnight rain. These picturesque water droplets are actually formed when water vapour in the air comes into direct contact with cold surfaces. This is why dew usually forms overnight, as surfaces on the ground will cool due to a loss of infrared radiation from the Sun. You're more likely to notice dew after a calm, cloudless night too, as cloudy skies help insulate the Earth and enable surfaces, where dew would otherwise form, to retain some level of heat.

Dew usually forms overnight when the ground cools

© DK Images; Dreamstime

RECORD BREAKERS
A LONG STREET

720km

BIGGEST VON KÁRMÁN VORTEX STREET

The longest Von Kármán vortex streets are usually to be found streaming from the Hallasan Volcano on South Korea's Jeju Island. The longest one measured to date ran for an incredible 720km (450mi) before it broke up.

DID YOU KNOW? Bees have been found to make use of vortices by taking advantage of energy created by the swirling eddies

What are Von Kármán vortices?

The science behind these mind-boggling, swirling cloud formations revealed

The area of fluid dynamics is one in which scientists are still getting to grips with, but back in 1911, a Hungarian called Theodore von Kármán worked with a flow tank to demonstrate the effect that a stationary body can have on the flow of a fluid passing over and around it.

As the fluid flow, such as a cloud formation, is disrupted by a cylinder – in nature this is generally an island or group of islands – the fluid is forced to either side of the barrier. The fluid flows around the obstruction, forming a boundary layer close to the object, which hugs it closely. As the flow continues, the boundary layer becomes a shear layer, which continues to move away from the barrier. If there is any kind of pressure imbalance coming from either side of the barrier, the side with greater pressure forces the fluid flow upward, separating it from the main flow and causing a swirling eddy. Having broken off one stream, the cloud then folds back on itself, causing the side with more pressure to be cut off and swirl away in the opposite rotational direction, creating a vortex.

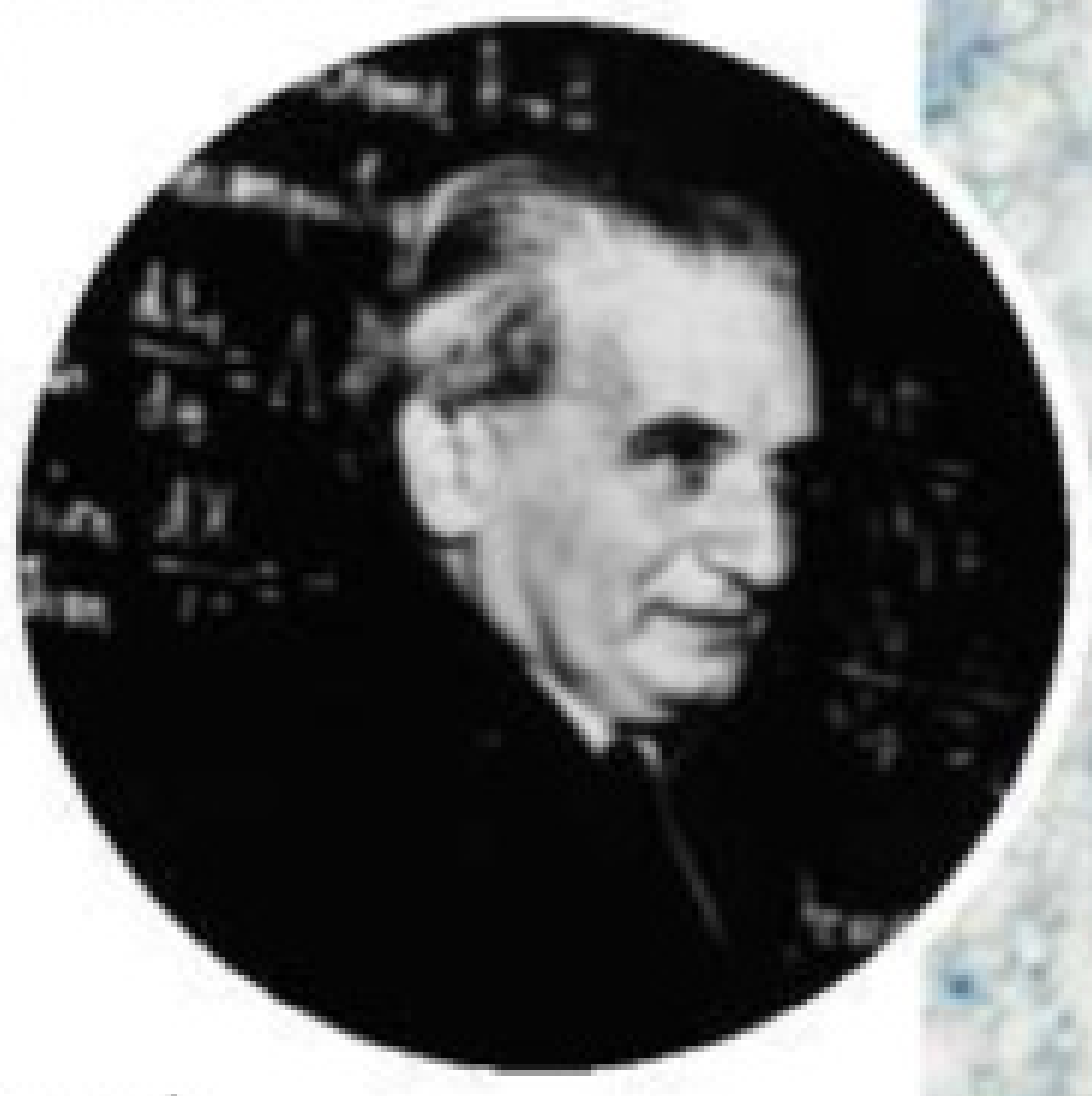
As the flow continues, the alternation of pressure imbalances continues, generating what is known as a 'street' of repeated vortices swirling in different directions (see image), pushed along by the fluid flow.

However, not all fluids that meet a barrier result in a Von Kármán vortex street. The pressure imbalance is measured by using Reynolds numbers, which represent the ratio of moving forces to stationary forces in a fluid flow. The higher the Reynolds number, the more likely a fluid flow will be turbulent rather than laminar (ie a smooth flow).

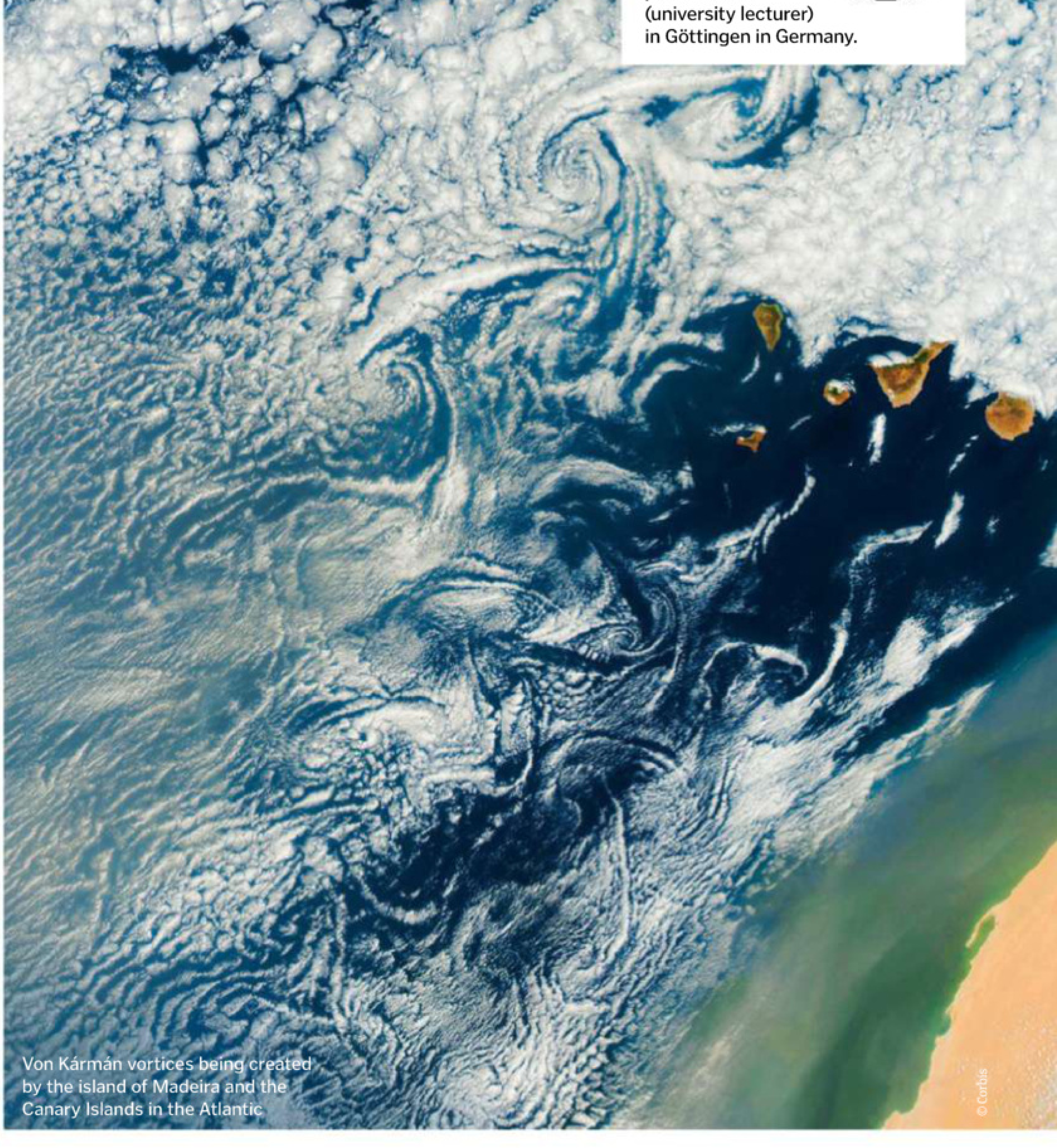
This phenomenon is most commonly seen in clouds as they are pushed along by the air current and disturbed by high-above-sea-level islands and mountains, but they can also be observed in the ocean and on ice.

The man behind the mystery

Theodore von Kármán was born in Budapest, Hungary, on 11 May 1881. His father, a philosophy and education professor, made him practise subjects such as geography and history. However, Von Kármán's natural maths ability shone through and he won the prestigious Eotvos Prize, which was awarded to the country's best maths and science student.



He made his famous breakthrough while working as a privatdozent (university lecturer) in Göttingen in Germany.



Von Kármán vortices being created by the island of Madeira and the Canary Islands in the Atlantic

© Corbis

How do waterfalls freeze?

Some waterfalls look as if they froze mid-flow, but how is this possible?

Ice forms on still bodies of fresh water like lakes when the temperature hits 0 degrees Celsius (32 degrees Fahrenheit) or below, but the physics of freezing becomes a lot more complicated in moving water.

Waterfalls don't immediately stop flowing and freeze over when the temperature plummets to freezing point. Quite the opposite, in fact. For a start, because the moving water is constantly mixing, the entire waterfall will cool uniformly, so it will take far longer for any noticeable change of state compared with still water under the same conditions.

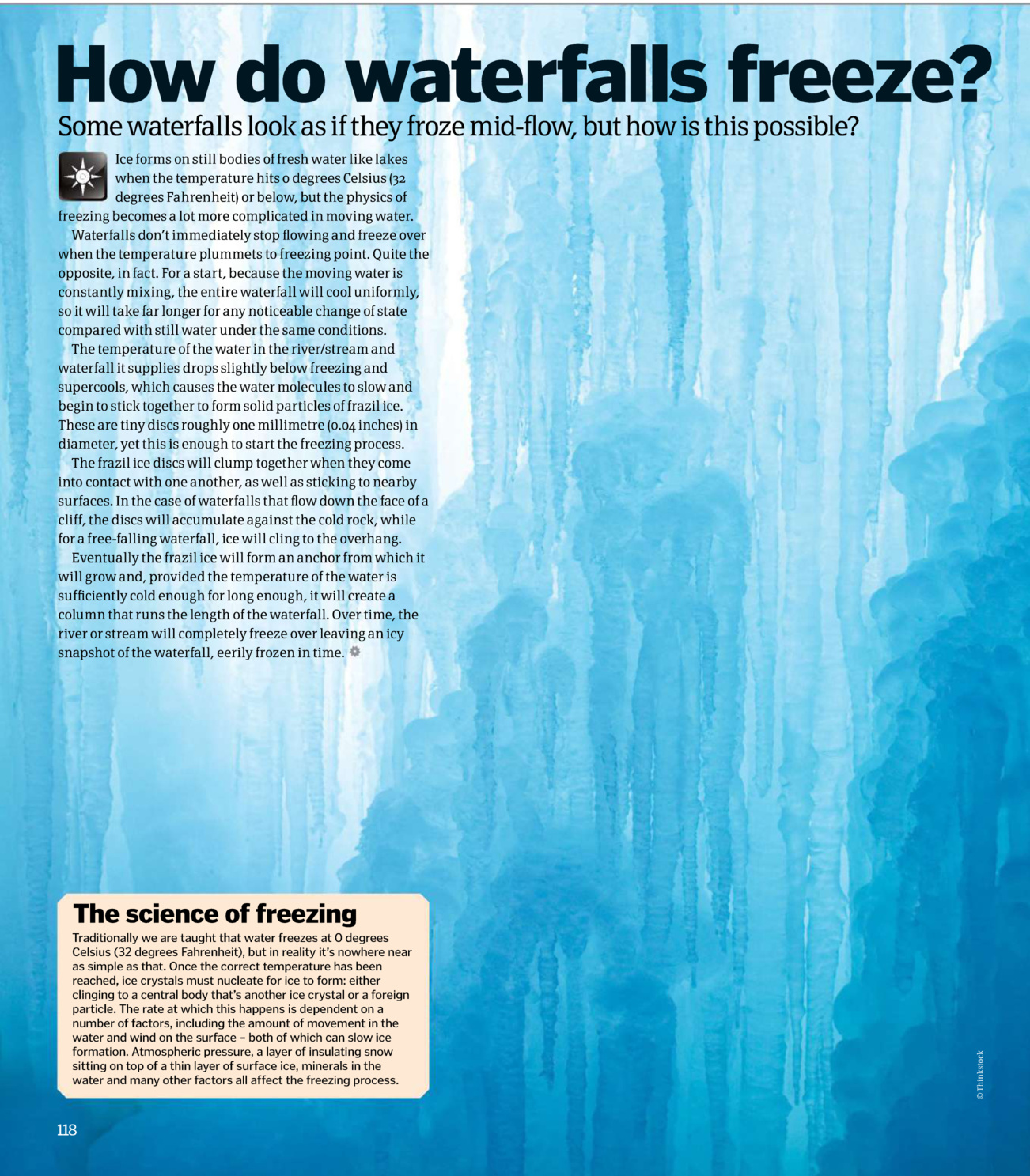
The temperature of the water in the river/stream and waterfall it supplies drops slightly below freezing and supercools, which causes the water molecules to slow and begin to stick together to form solid particles of frazil ice. These are tiny discs roughly one millimetre (0.04 inches) in diameter, yet this is enough to start the freezing process.

The frazil ice discs will clump together when they come into contact with one another, as well as sticking to nearby surfaces. In the case of waterfalls that flow down the face of a cliff, the discs will accumulate against the cold rock, while for a free-falling waterfall, ice will cling to the overhang.

Eventually the frazil ice will form an anchor from which it will grow and, provided the temperature of the water is sufficiently cold enough for long enough, it will create a column that runs the length of the waterfall. Over time, the river or stream will completely freeze over leaving an icy snapshot of the waterfall, eerily frozen in time.

The science of freezing

Traditionally we are taught that water freezes at 0 degrees Celsius (32 degrees Fahrenheit), but in reality it's nowhere near as simple as that. Once the correct temperature has been reached, ice crystals must nucleate for ice to form: either clinging to a central body that's another ice crystal or a foreign particle. The rate at which this happens is dependent on a number of factors, including the amount of movement in the water and wind on the surface – both of which can slow ice formation. Atmospheric pressure, a layer of insulating snow sitting on top of a thin layer of surface ice, minerals in the water and many other factors all affect the freezing process.



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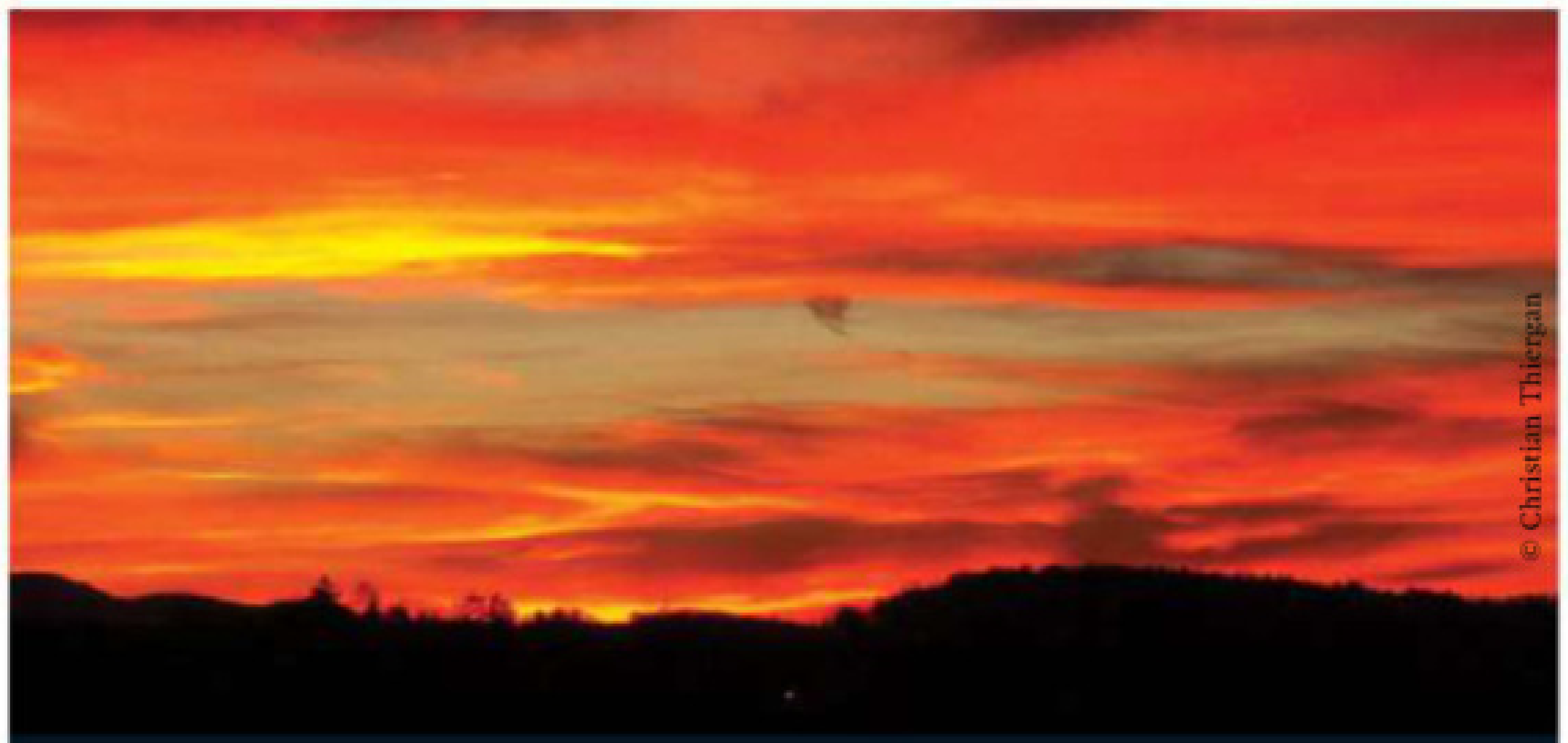

© Christian Thiergan

Why do we get red sky at night?

Just how true is the famous phrase, and what causes the sky to turn red?

A red glow can often appear in the sky at dawn or dusk. The reason behind this red tint is a simple one, related to how light travels from the Sun up into the sky at this time. The low position of the Sun, coupled with the thick layer of atmosphere the light must travel through, cause short wavelengths to scatter. Only the longest wavelengths make it through, explaining why we only see a red colour displayed.

'Red sky at night, sailor's delight' came into use before scientific weather forecasting was developed. It is based on the assumption that weather systems generally move from west to east, a red glow at night, indicating a clear sky in the west, therefore suggesting that bad weather systems have passed through.

What is the wind-chill factor?

Why does this phenomenon make it feel colder than it really is?

The wind-chill factor describes the rate at which your body loses heat due to wind and low temperatures. When it's chilly outside you will of course feel the cold. However, when fast-moving air (ie wind) blows across your exposed skin you will feel even colder. This is because as wind speed increases, the rate at which heat is carried away from the body also increases, first causing an external temperature drop, then later – and more dangerously – a reduction in internal body heat.

The NOAA's National Weather Service's windchill index shows the serious implications. For example, if the temperature is -18 degrees Celsius (0 degrees Fahrenheit) and the wind speed is 24 kilometres (15 miles) per hour, the wind-chill factor would be -28 degrees Celsius (-19 degrees Fahrenheit) and human skin would experience frostbite in just 30 minutes.

The smell of rain

Find out why precipitation creates a distinctive aroma that's the same all over the world

It's possible to smell rain before it has even fallen. Lightning has the power to split atmospheric nitrogen and oxygen molecules into individual atoms. These atoms then react to form nitric oxide, which in turn can interact with other chemicals to form ozone – the aroma of which is a bit like chlorine and a specific smell we've grown to associate with rain. When the scent carries on the wind, we can predict the rain before it falls.

Another smell associated with rain is petrichor – a term coined by a couple of Australian scientists in the mid-Sixties. After a dry spell of weather, the first rain that falls brings with it a very particular aroma that is the same no matter where you are. Two chemicals are responsible for the production of this indescribable odour called petrichor. One of the two chemicals is released by a specific bacteria found in the earth; the other is an oil secreted by thirsty plants. These compounds combine on the ground and, when it rains, the smell of petrichor will fill your nostrils.

© Thinkstock

Cave weather

Explore one of China's most stunning cave systems to learn why it has developed its own microclimate

Cut off from the Sun, rain and wind that we experience on the surface, you might assume meteorological conditions in caves never change. However, the reality is that their climates do vary significantly – not only from location to location, but within individual caves over time. Indeed, some examples, like the Er Wang Dong cave system in Chongqing Province, China (main picture), even host their own weather. Ultimately this is because very few caves are 100 per cent cut off from their surroundings.

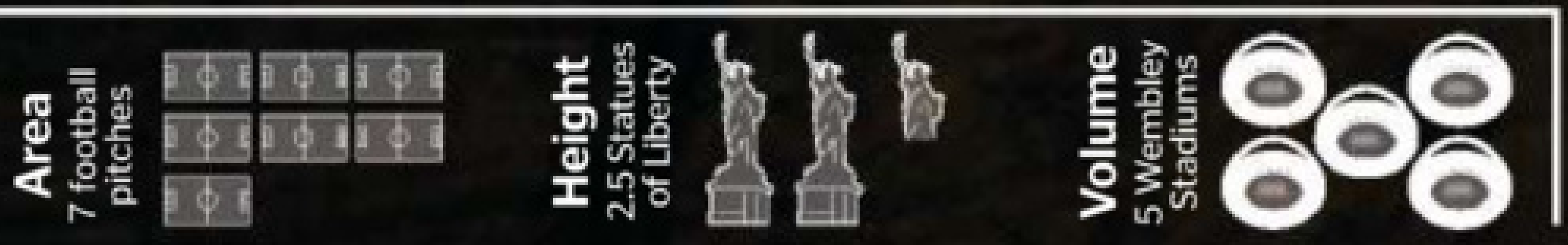
In the case of Er Wang Dong, it all comes down to an imbalance in the local topology. There are several tunnels around the cave system's perimeter where wind can blow in. Once trapped underground air from outside gains moisture, pooling into huge chambers like Cloud Ladder Hall – the second-biggest natural cavern in the world with a volume of 6 million cubic metres (211.9 million cubic feet). Once in an open chamber this humid air rises.

While there are numerous entrances into this subterranean complex, exits are few and far between. In Cloud Ladder Hall's case, it's a hole in the roof some 250 metres (820 feet) above the floor, leading to a bottleneck effect. As the damp air hits a cooler band near the exit, tiny water droplets condense out to create wispy mist and fog. In other chambers plants and underground waterways can also contribute to underground weather.

Even caves without any direct contact with the outside world can still experience climatic variations, as they are subject to fluctuations in atmospheric pressure and geothermal activity, where the heat from Earth's core emanates through the rocky floor. However, in such caves, changes are more evenly distributed so take place over longer time frames.

Here, fog clouds can be seen in the deep sinkhole at the entrance of the caves while the Sun shines above it

Sizing up Cloud Ladder Hall



10mn m³

BIGGEST UNDERGROUND CHAMBER

The Cloud Ladder Hall is only beaten by the Sarawak Chamber in Borneo in scale. Sarawak is estimated to have almost double the volume of the Chinese cavern, in the range of 10mn m^3 (353.1mn ft^3).

DID YOU KNOW? *Although previously mined, the Er Wang Dong cave system was only properly explored for the first time in 2013*

© Robbie Shone

The ozone layer explained

We may hear about it a lot, and mainly how we're slowly destroying it, but just what is the ozone layer?

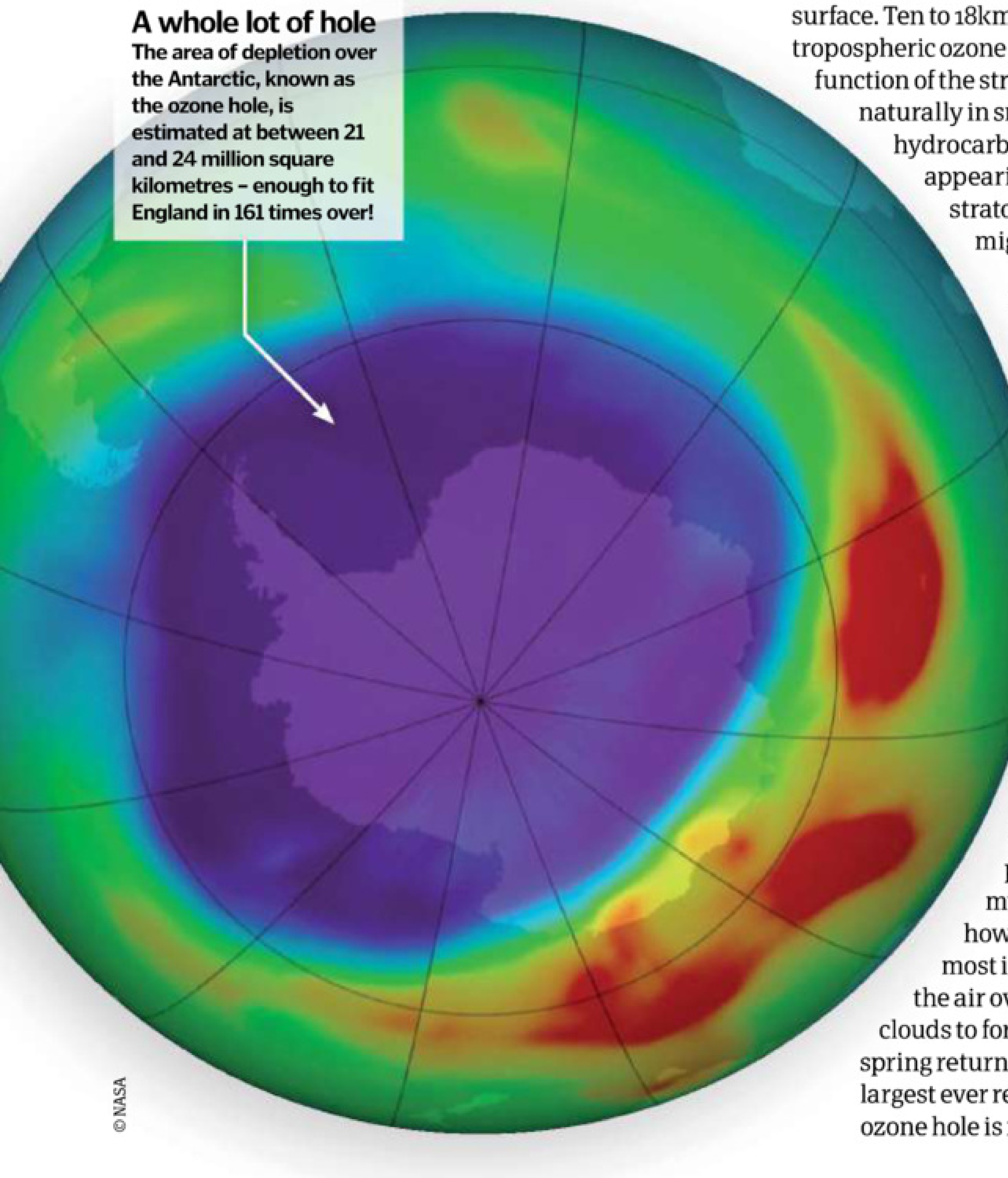
The ozone layer is essentially Mother Earth's safety net, residing some 50 kilometres above the planet's surface. Created from O_3, or ozone gas, it is up to 20 kilometres thick and 90 per cent of this gas can be found up on the Earth's stratosphere. This protective gas is vital to the nurturing of life on our planet, and here's why.

Ozone gases act as a shield against ultra violet, or UVB, radiation. These harmful emissions are sent through the Sun's rays, and without the ozone would severely affect the planet's ecological balance, damaging bio-diversity. UVB rays reduce plankton levels in the ocean, subsequently diminishing fish stock. Plant growth would also diminish in turn disrupting agricultural productivity. This would in turn affect the human populace, who would be exposed to an increase in skin-related diseases such as cancer.

So how does the ozone protect us? Ozone molecules consist of three oxygen atoms, hence the chemical formula O_3. Stratospheric ozone absorbs UVB high-energy radiation, as well as energetic electrons, which in turn splits the O_3 into an O atom and an O_2 molecule. When the O atom soon encounters another O_2 molecule they re-merge and recreate O_3. This means that the ozone layer absorbs the UVB without being consumed. The ozone layer absorbs up to 99 per cent of the Sun's high frequency UV light rays, transforming this into heat after its combustible atomic reaction, therefore creating the stratosphere itself. This effectively incubates life on Earth.

But ozone doesn't reside only in the world above. This gas is also present in the layer around the Earth's surface. Ten to 18km above us, this is known as the tropospheric ozone or 'bad ozone', comparative to the function of the stratosphere. This ozone occurs naturally in small doses, initiating the removal of hydrocarbons, released by plants and soil, or appearing from small amounts of stratospheric ozone, which occasionally migrate down to the Earth's surface.

However, it gets a bad reputation due to its interaction of ultraviolet light, with volatile organic compounds and nitrogen oxides, emitted by fossil-fuel powered machines and internal combustion engines. This produces high levels of ozone, which are formed in high temperature conditions, ultimately toxic to all forms of organic life.



A whole lot of hole

The area of depletion over the Antarctic, known as the ozone hole, is estimated at between 21 and 24 million square kilometres – enough to fit England in 161 times over!

© NASA

How big is the hole in the ozone layer?

The ozone hole refers to an area of depletion over the Antarctic region of Earth. The planet's ozone records a decline of four per cent per decade in total volume but much larger loses are recorded in the stratospheric ozone over Earth's polar region, however this is seasonal condition. These areas' unique atmospheric conditions see the most impact. Strong winds blow around the continent forming a polar vortex, isolating the air over Antarctica from the rest of the world. This allows special polar stratospheric clouds to form at about 80,000 feet altitude. These concentrate atmosphere pollutant. When spring returns after the sunless winter period the ozone is depleted causing the ozone hole. The largest ever recorded ozone hole occurred in 2006, at 20.6 million square miles. At present the ozone hole is recorded at between 21 and 24 million square kilometres.

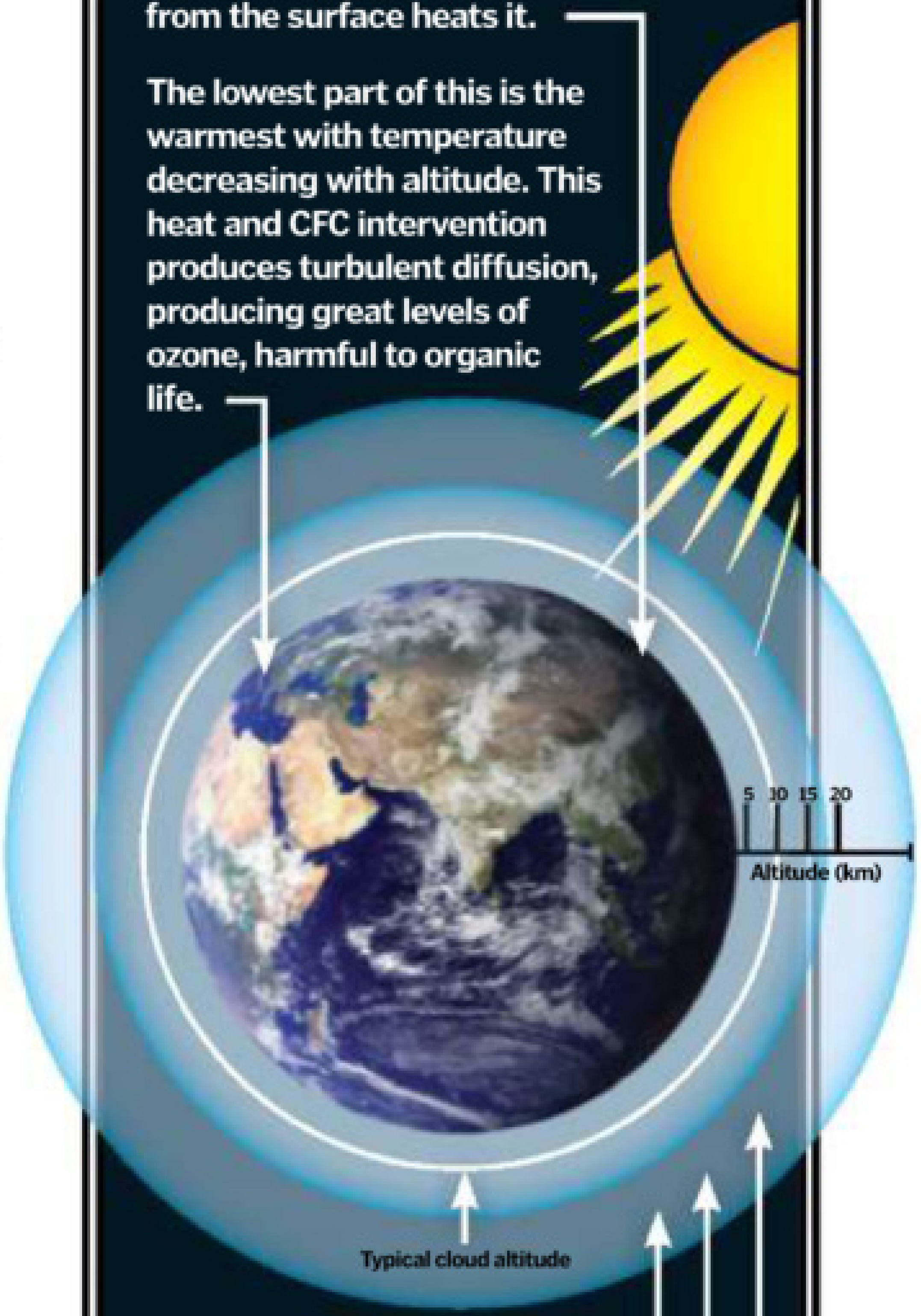
The structure of the Earth's atmosphere

Here's how the ozone extends from the Earth's surface

Tropospheric ozone

Starts at ground level, with an altitude of up to 15 kilometres. Energy transfer from the surface heats it.

The lowest part of this is the warmest with temperature decreasing with altitude. This heat and CFC intervention produces turbulent diffusion, producing great levels of ozone, harmful to organic life.



Stratospheric ozone

Between ten and 50 kilometres up from the stratopause. It contains up to 90 per cent of Earth's ozone.

The stratosphere contains the highest level of ozone on the planet, with two to eight parts per million. This reacts with UVB to produce what we know as the ozone layer.

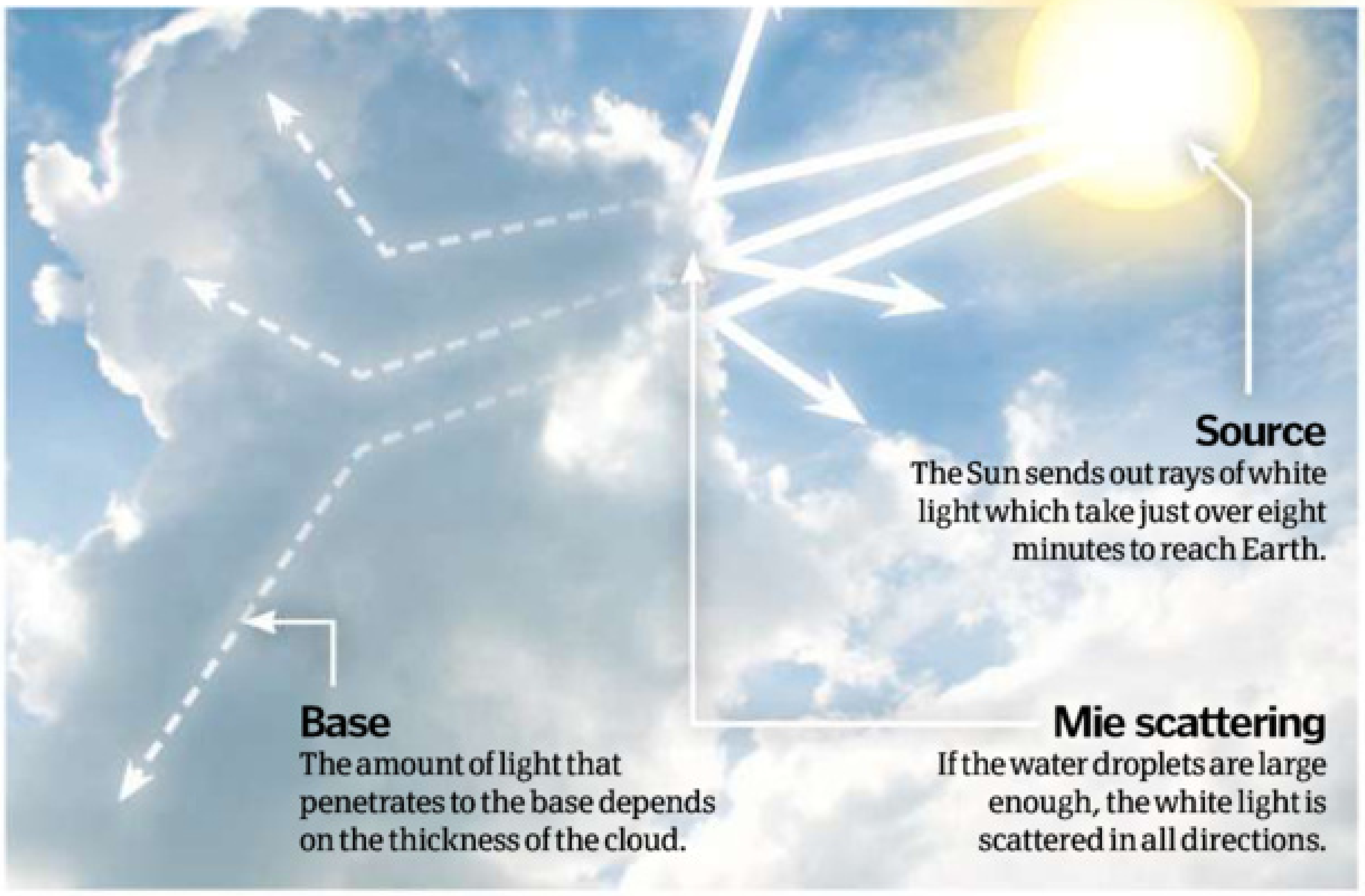
The stratosphere is layered in temperature due to UVB absorption. Heat increases with altitude, with the top of the stratosphere has a temperature up to -3°C.

Why are clouds white?

Discover the basic scientific principle that makes clouds white

Clouds are formed when humid air, or water vapour, rises and cools. The vapour expands and becomes tiny droplets. Clouds only get their white appearance if these droplets become large enough to scatter visible light in all directions; this is known as Mie scattering.

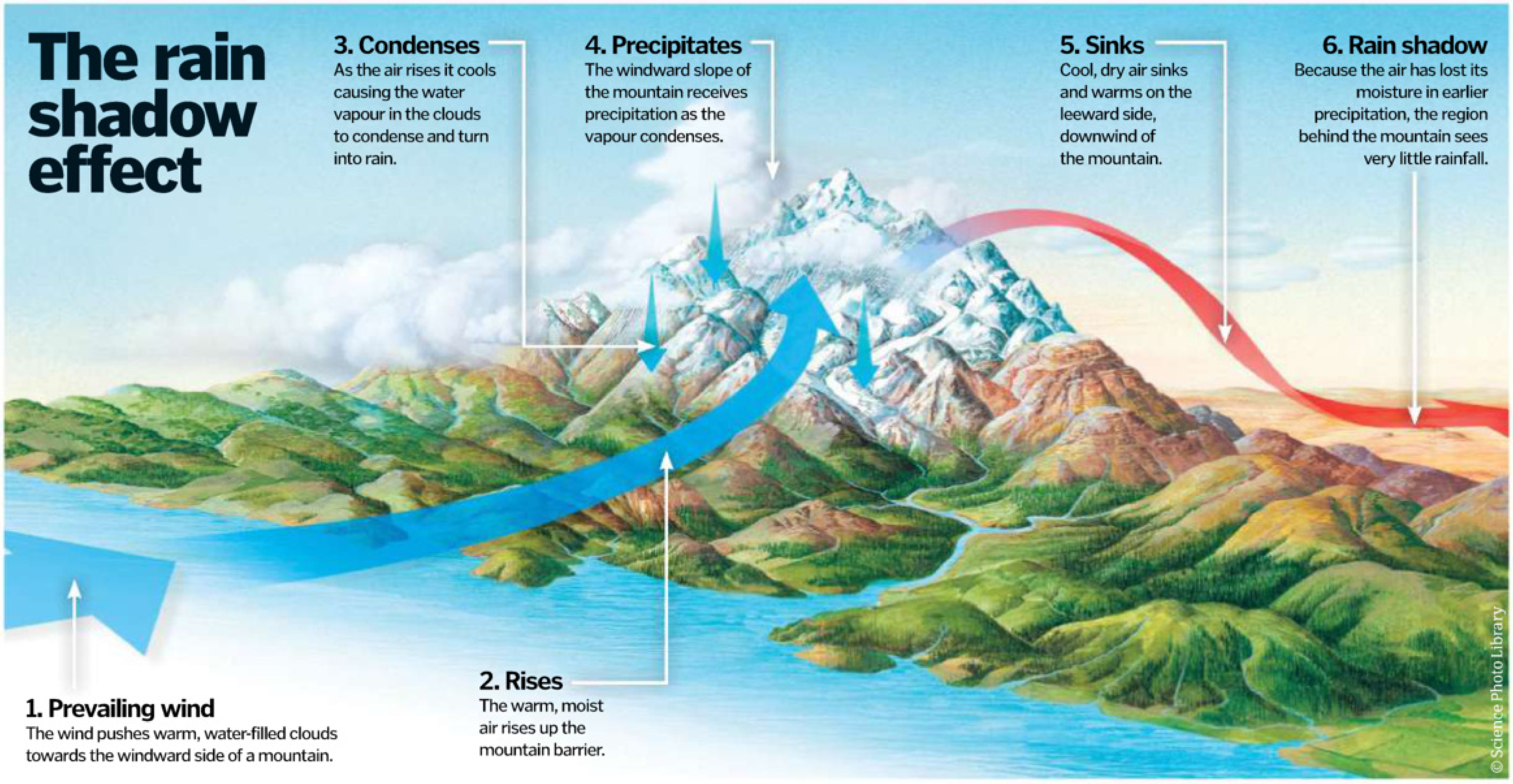
Visible light is a form of electromagnetic radiation, with each different colour that we can see having a different wavelength. White light, however, contains equal amounts of all colours of the spectrum. When sunlight hits the individual water droplets in a cloud all wavelengths of light are scattered evenly in all directions. However, very thick clouds, which are made of very densely packed water droplets, will appear darker – like storm clouds – because less of the incoming light from the Sun can penetrate to the base. From above in an aeroplane, though, a storm cloud will still appear white – it only looks dark from the ground because little sunlight is not getting through.



Source
The Sun sends out rays of white light which take just over eight minutes to reach Earth.

Base
The amount of light that penetrates to the base depends on the thickness of the cloud.

Mie scattering
If the water droplets are large enough, the white light is scattered in all directions.



The rain shadow effect

1. Prevailing wind
The wind pushes warm, water-filled clouds towards the windward side of a mountain.

2. Rises
The warm, moist air rises up the mountain barrier.

3. Condenses
As the air rises it cools causing the water vapour in the clouds to condense and turn into rain.

4. Precipitates
The windward slope of the mountain receives precipitation as the vapour condenses.

5. Sinks
Cool, dry air sinks and warms on the leeward side, downwind of the mountain.

6. Rain shadow
Because the air has lost its moisture in earlier precipitation, the region behind the mountain sees very little rainfall.

© Science Photo Library

Rain shadows

Why does this weather phenomenon cause deserts to form on one side of a mountain?

A rain shadow is an area that receives very little precipitation due to a substantial obstruction, most commonly a large mountain.

Such an obstruction blocks the path of moisture-rich rain clouds. Due to a process of cooling and condensation, a shadow area of dry conditions is likely to develop beyond this barrier.

Essentially this means that the windward side of a mountain receives plenty of precipitation where as the leeward side might be left extremely dry. This can result in a dramatic contrast of conditions with the formation of a desert on one side but not the other. The warm, dry breeze that blows down the leeward side of a slope is known as a foehn wind.

How the seasons work

Get out your flashlight and a beach ball, it's time to talk about tilt

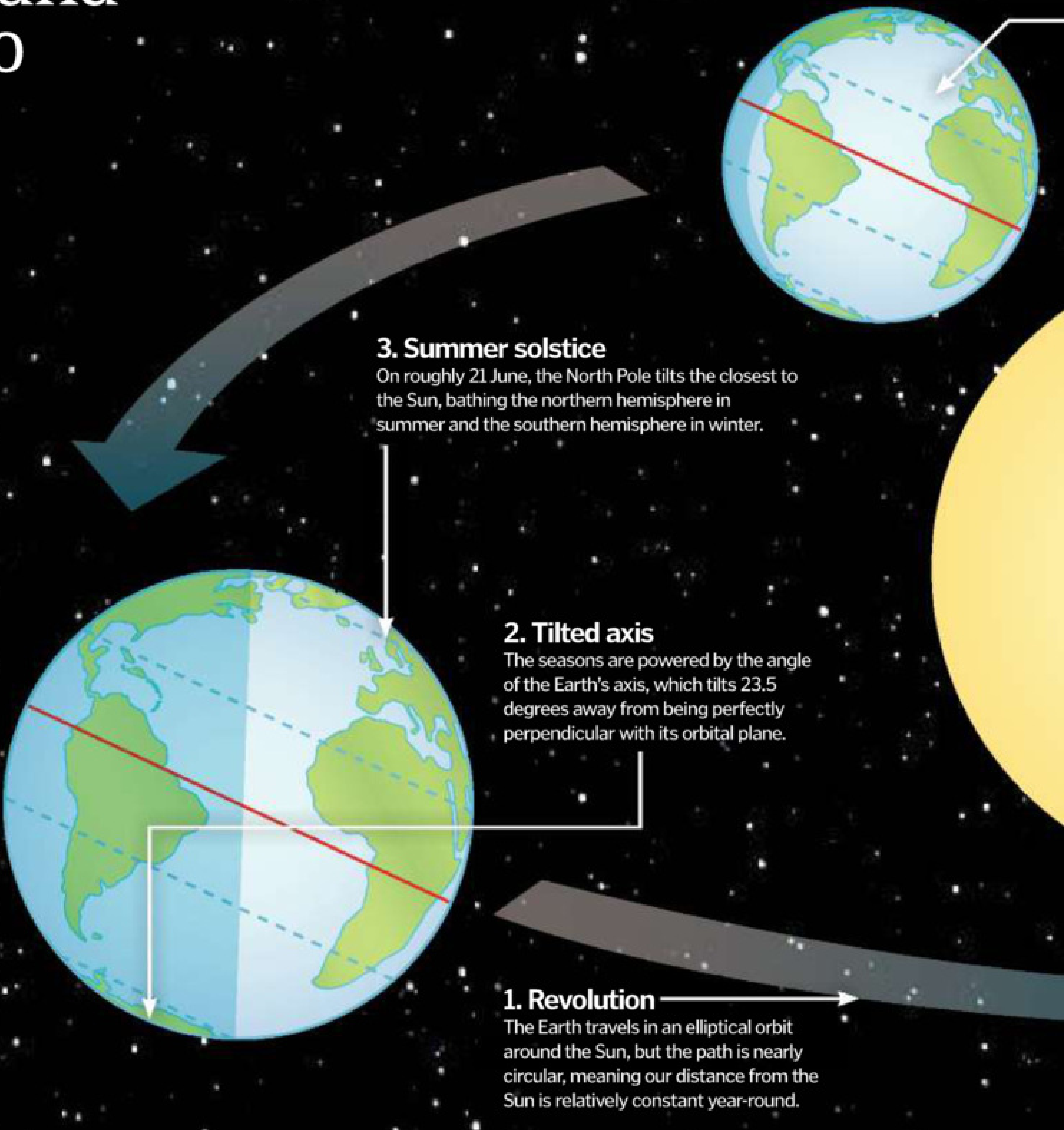
The Earth is a wonky planet. Every year we make a complete near-circular revolution around the Sun, but every day our planet spins around a lopsided axis. This imaginary line that runs through the centre of the planet from the North Pole to the South Pole is tilted at a 23.5° angle, and this wonky tilt is the reason for the seasons.

During June and July in the northern hemisphere, the North Pole is tilted toward the Sun and South Pole tilted away. This means that solar radiation hits the northern hemisphere "head on" and is absorbed in a more concentrated area. Because the southern hemisphere is angled away from the Sun, the same amount of solar radiation is spread across a much larger surface area.

But differences in solar intensity aren't enough to create summer and winter. The tilt of the axis also creates radical differences in the length of solar exposure, what we define as daylight. If we go back to our June and July example, the northern hemisphere is directly facing the Sun, which means the Sun carves a high path across the sky, creating longer daylight hours. In the southern hemisphere, the Sun travels much closer to the horizon, which limits daylight hours significantly.

The combination of longer days and concentrated sunlight gives us summer. Shorter days and dispersed solar energy gives us winter. Autumn and spring mark the transitional periods when days are getting longer or shorter and temperature variations tend to be less extreme.

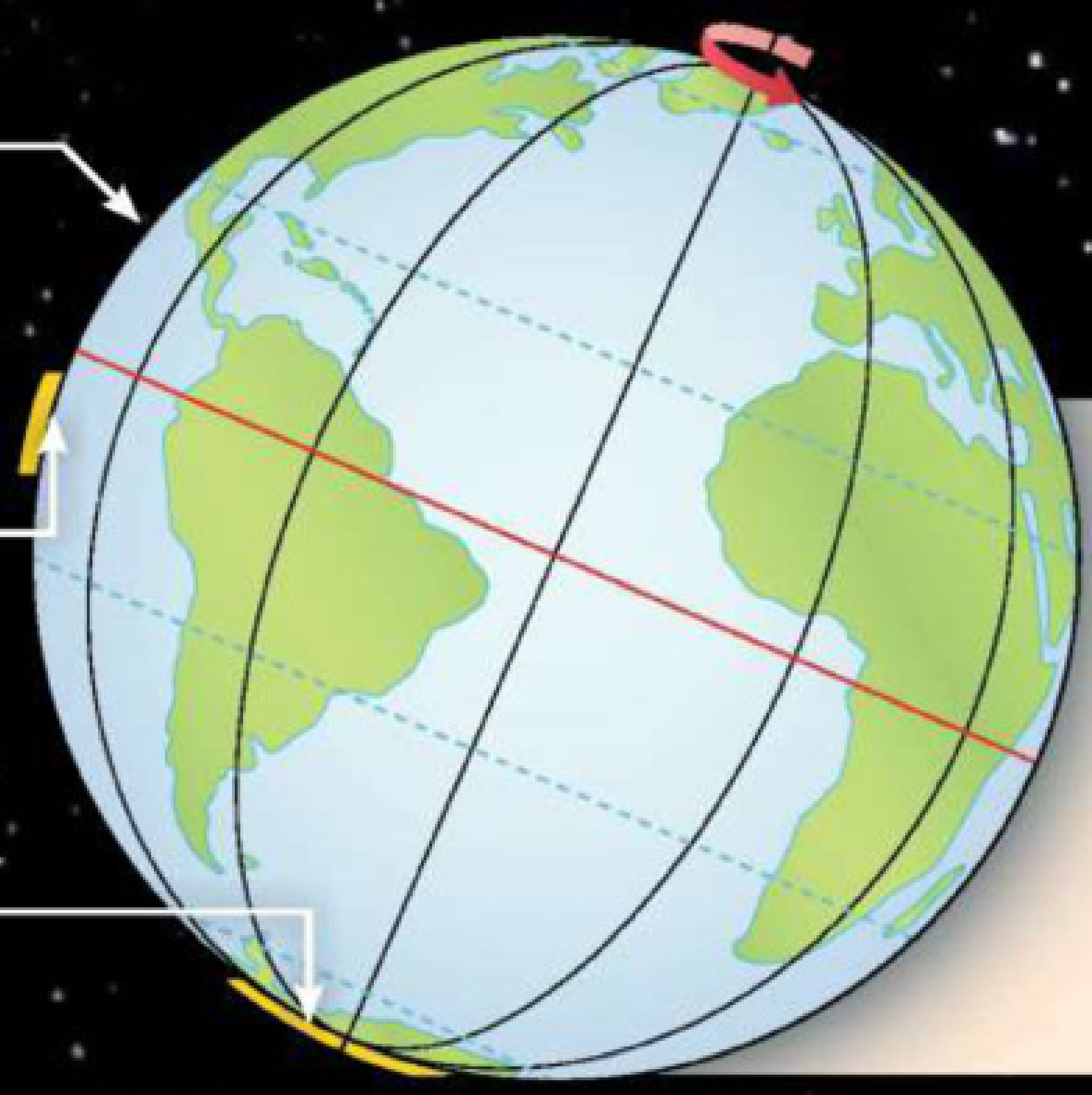
January in Australia is hot enough to cause bush fires



3. Summer solstice
On roughly 21 June, the North Pole tilts the closest to the Sun, bathing the northern hemisphere in summer and the southern hemisphere in winter.

2. Tilted axis
The seasons are powered by the angle of the Earth's axis, which tilts 23.5 degrees away from being perfectly perpendicular with its orbital plane.

1. Revolution
The Earth travels in an elliptical orbit around the Sun, but the path is nearly circular, meaning our distance from the Sun is relatively constant year-round.



1. The tropics
All year long, the region within the tropics of Cancer and Capricorn receives the most direct and intense sunlight.

2. Concentrated surface area
Since the Sun's rays strike the region around the equator at nearly a 90° angle, the intensity of the radiation is concentrated on a relatively small surface area.

3. Scattered surface area
Near the poles, the Sun's angle of incidence is much lower, meaning solar radiation scatters across a much larger surface area, losing its intensity.

5 TOP FACTS
SEASONS ON OTHER PLANETS

Long summer

1 Because Neptune is so far away from the Sun, it takes over 164 Earth years to complete a revolution. That makes its summer around 40 years long.

"Tropical" Venus

2 Since Venus' axis only tilts at a 3° angle, all of its seasons are roughly the same, which results in a rather steamy 750K all year round.

Serious tilt

3 Uranus spins on an axis tilted at 98°, and much of the planet is bathed in continuous darkness or continuous light for 20 years at a time.

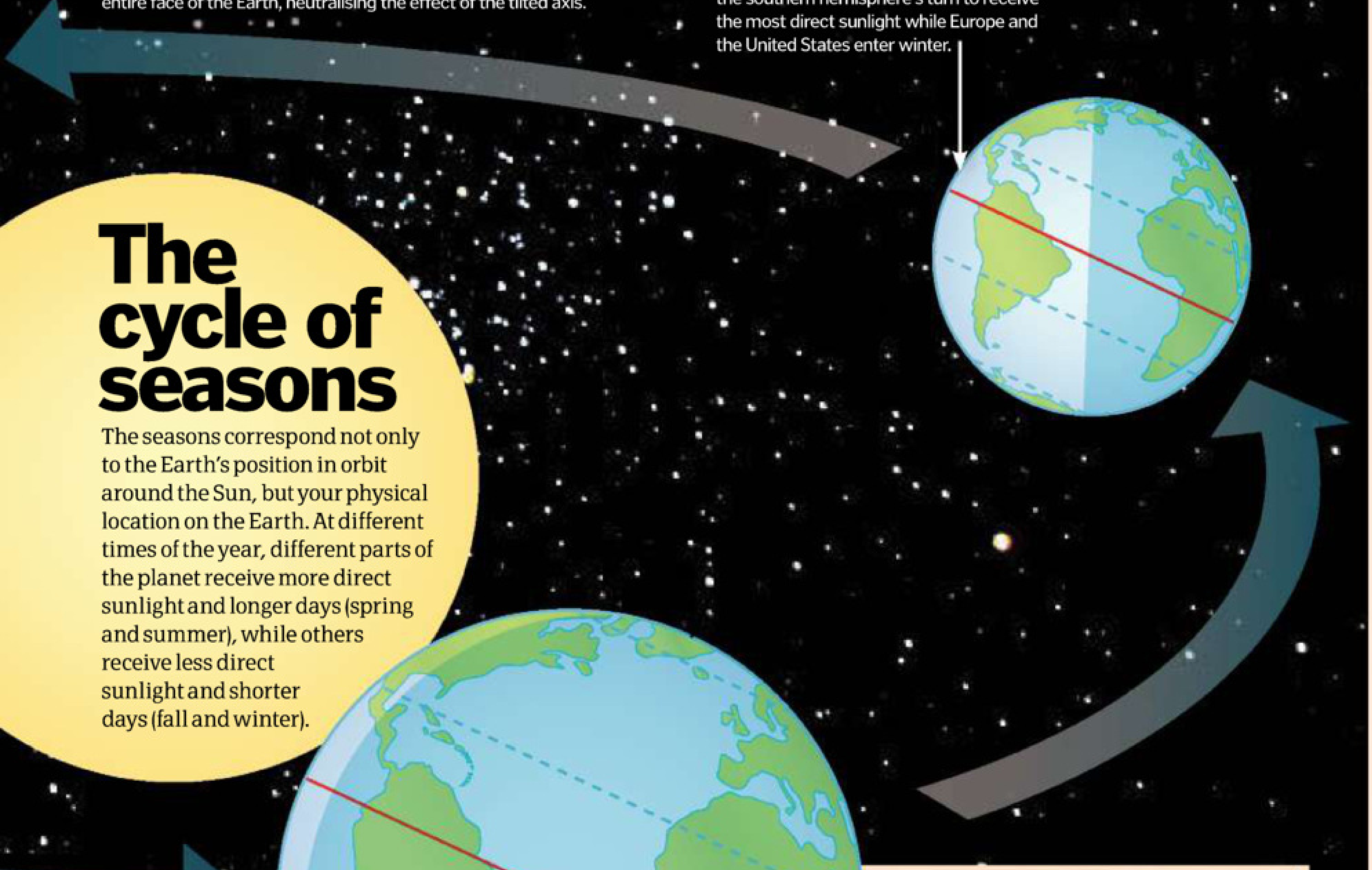
Springtime on Uranus

4 There are no April showers on Uranus. When spring arrives after 20 years of darkness, the warming atmosphere generates violent storms.

Long days

5 Due to its slow rotation on its axis and rapid movement around the Sun, a day on Mercury is the equivalent of 176 Earth days.

DID YOU KNOW? Contrary to common sense, the Earth is closest to the Sun (147,300,000km) on or around 3 January



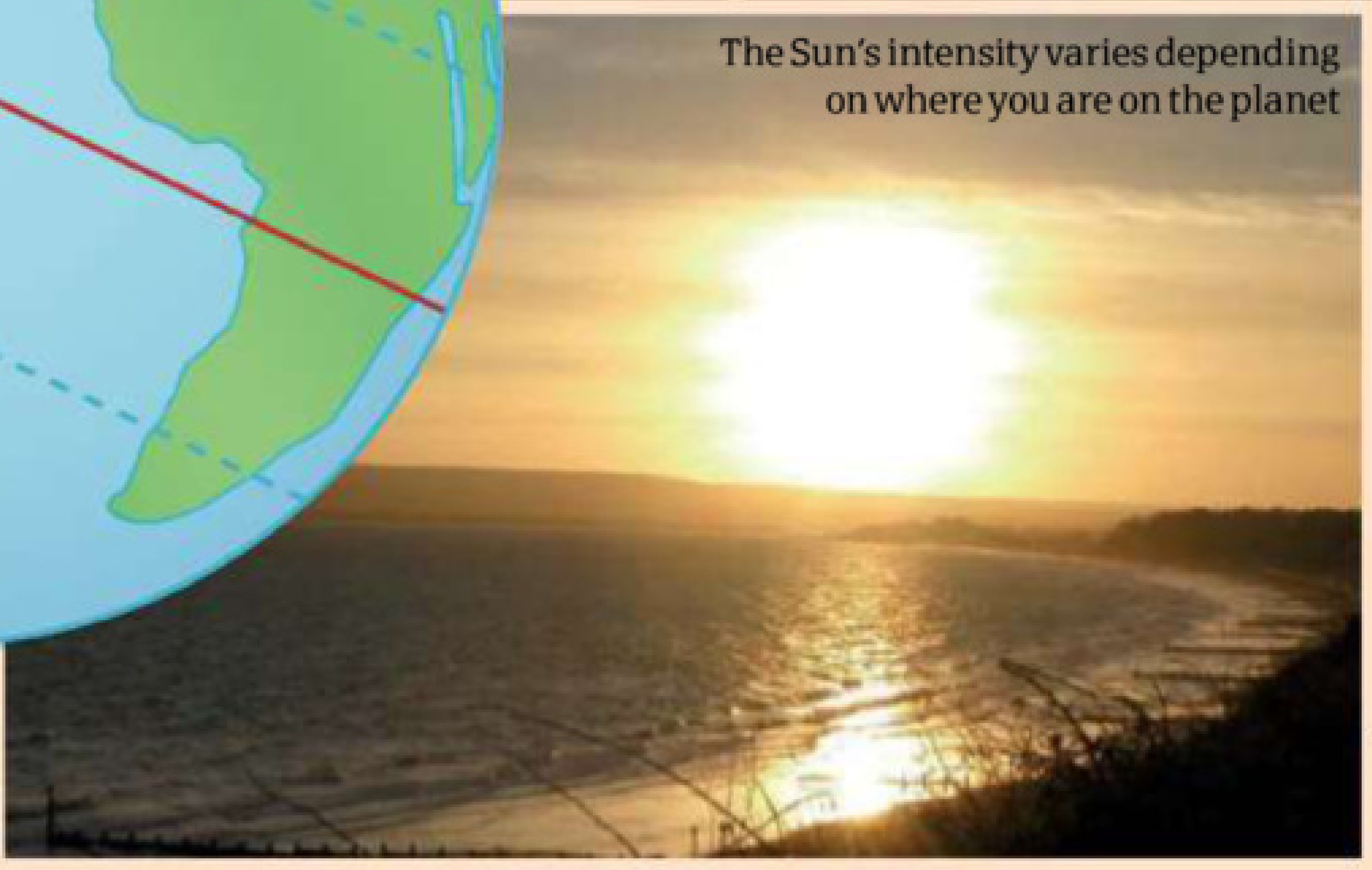
5. Vernal equinox
At this point in the orbit, the Sun shines evenly across the entire face of the Earth, neutralising the effect of the tilted axis.

4. Winter solstice
At the opposite end of the Earth's orbit, it's the southern hemisphere's turn to receive the most direct sunlight while Europe and the United States enter winter.

The cycle of seasons

The seasons correspond not only to the Earth's position in orbit around the Sun, but your physical location on the Earth. At different times of the year, different parts of the planet receive more direct sunlight and longer days (spring and summer), while others receive less direct sunlight and shorter days (fall and winter).

6. Autumnal equinox
As with the vernal equinox, the first day of autumn has exactly 12 hours of daylight and 12 hours of darkness.



The Sun's intensity varies depending on where you are on the planet

Solar intensity

It gets hotter as you move closer to the equator because the region between the tropic of Cancer and the tropic of Capricorn receives more direct and concentrated solar radiation.

The reason for this is not because the tropics are 'closer' to the Sun than other parts of the planet. It has to do with something called the 'angle of incidence'. During the vernal and autumnal equinoxes, the Sun's rays strike the equator at a precise 90° angle. Since the solar radiation rains down on the Earth so directly, its intensity is concentrated in a relatively small area. Compare this with the solar exposure of Iceland, which sits right on the Arctic circle at roughly 66° north of the equator. During the autumnal equinox, the Sun's rays hit Iceland on a much shallower angle of 70°, spreading their radiation across a much larger surface area, thereby decreasing their intensity.

Solstice vs equinox

The winter solstice is commonly referred to as the "shortest day of the year". Although 21 December is still 24 hours long, it has the fewest hours of sunlight. On this day, the North Pole is tilted the furthest from the Sun, causing the Sun to trace a low path in the sky. As the months pass, the Sun's course drifts upward until we reach the vernal equinox, a day with exactly 12 hours of light and 12 hours of darkness. Around 21 June, the North Pole tilts closest to the Sun, the Sun rides high in the sky and we have the summer solstice, the longest day of the year. As the Sun's path sinks back toward the horizon, we reach the autumnal equinox, the second time all year when day and night are perfectly equal.

Here comes the Sun… flower

Seasons at the top of the world

For people living at the equator, seasons are virtually meaningless. The closer you are to the equator, the less your weather is affected by the tilt of the Earth. If you tilt a globe back and forth, the top and bottom appear to move further away from you, while the middle will remain relatively central.

In high-latitude regions the differences between seasons are extreme. In the dead of winter in northern Norway, the northern hemisphere is tilted so far away from the Sun that it doesn't peak over the horizon for two months. In the middle of summer, the Sun travels directly overhead, tracing a loop through the sky that holds back the night for 2.5 months.

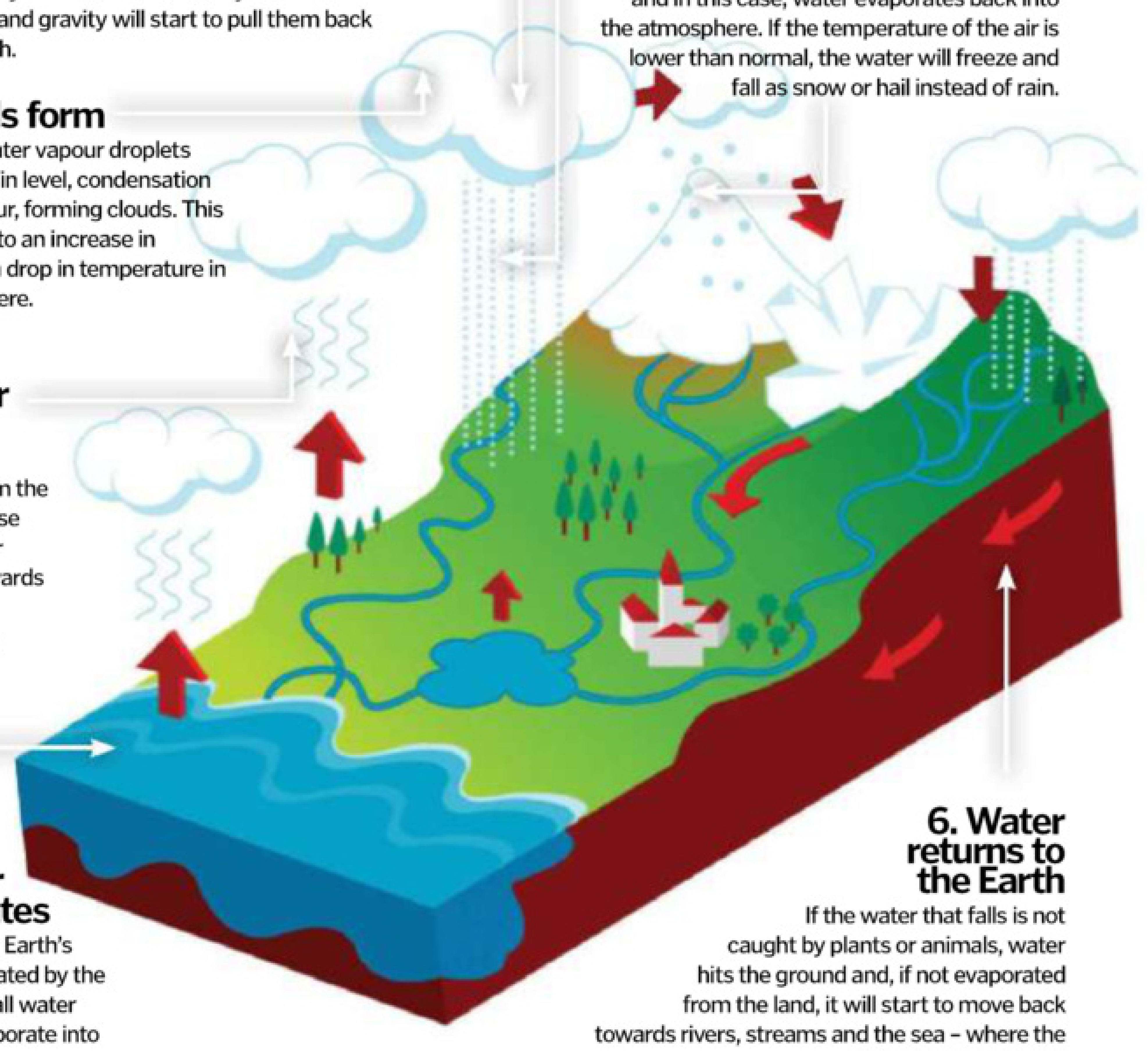
Background image courtesy of NASA

Why, and how, does it rain?

In England, rain is a more common occurrence than most of us would like, but it is very important for the maintenance of our ecosystem

Rain is defined as liquid precipitation. It is formed high above the ground in clouds by water vapour coming together into large droplets that become too heavy for the air to support. Gatherings of condensed water vapour are called clouds, and this is where rain comes from. Although a large amount of water is held in each cloud, rain does not fall all at once from the cloud because the water droplets grow at different speeds, with the fastest growing droplets becoming heavier quicker and falling first, the slower growing ones falling after.

Although scientists are not sure if there is water on other planets, the phenomenon of rain has occasionally been recorded. This rain involves other liquids, such as methane which falls on Titan, Saturn's moon, and sulphuric acid which falls on Venus.



1. Water evaporates
Water on the Earth's surface is heated by the Sun, and small water droplets evaporate into the air.

2. Water vapour travels
The heat from the Sun pulls these water vapour droplets upwards into the atmosphere.

3. Clouds form
When the water vapour droplets reach a certain level, condensation starts to occur, forming clouds. This is due either to an increase in humidity or a drop in temperature in the atmosphere.

4. Rain forms
As more water vapour droplets gather within the cloud, they start to merge and become larger. Eventually they will become too heavy to be held in the atmosphere and gravity will start to pull them back towards Earth.

5. Rain falls
Sometimes water will not make it back to Earth, due to the air not being humid enough, and in this case, water evaporates back into the atmosphere. If the temperature of the air is lower than normal, the water will freeze and fall as snow or hail instead of rain.

6. Water returns to the Earth
If the water that falls is not caught by plants or animals, water hits the ground and, if not evaporated from the land, it will start to move back towards rivers, streams and the sea – where the process begins again.

What are fog, mist and haze?

Discover how fog lets you walk through the clouds without leaving the ground

Fog and mist are ground-level clouds: they are formed of airborne water droplets. Fog is denser than mist – it prevents you seeing further than 1km ahead. In mist, you can see between one and 2km. Haze also makes the air less clear. But unlike mist and fog, it's caused by airborne particles of soot, salt or dust.

Fog and mist form when moist air near the ground cools enough that condensation occurs. Condensation is the mechanism that mists a mirror when you breathe on it. Air contains water vapour – the warmer the air, the more vapour it can hold. When the warm air in your breath hits the colder mirror, it cools. The vapour the air can no longer hold condenses out, ie water droplets form on the mirror's surface. Haze particles can be a precursor to fog because, in fog, water droplets form on particles in the air.

DID YOU KNOW?

The 'Asian brown cloud' is a wintertime pollution haze over parts of Asia. It's big enough to see from space.

© Milazinkova 2009

Double, or multiple, rainbows are only visible to the naked eye when the incoming sunlight is unhindered by atmospheric effects, so is very intense

Double rainbows

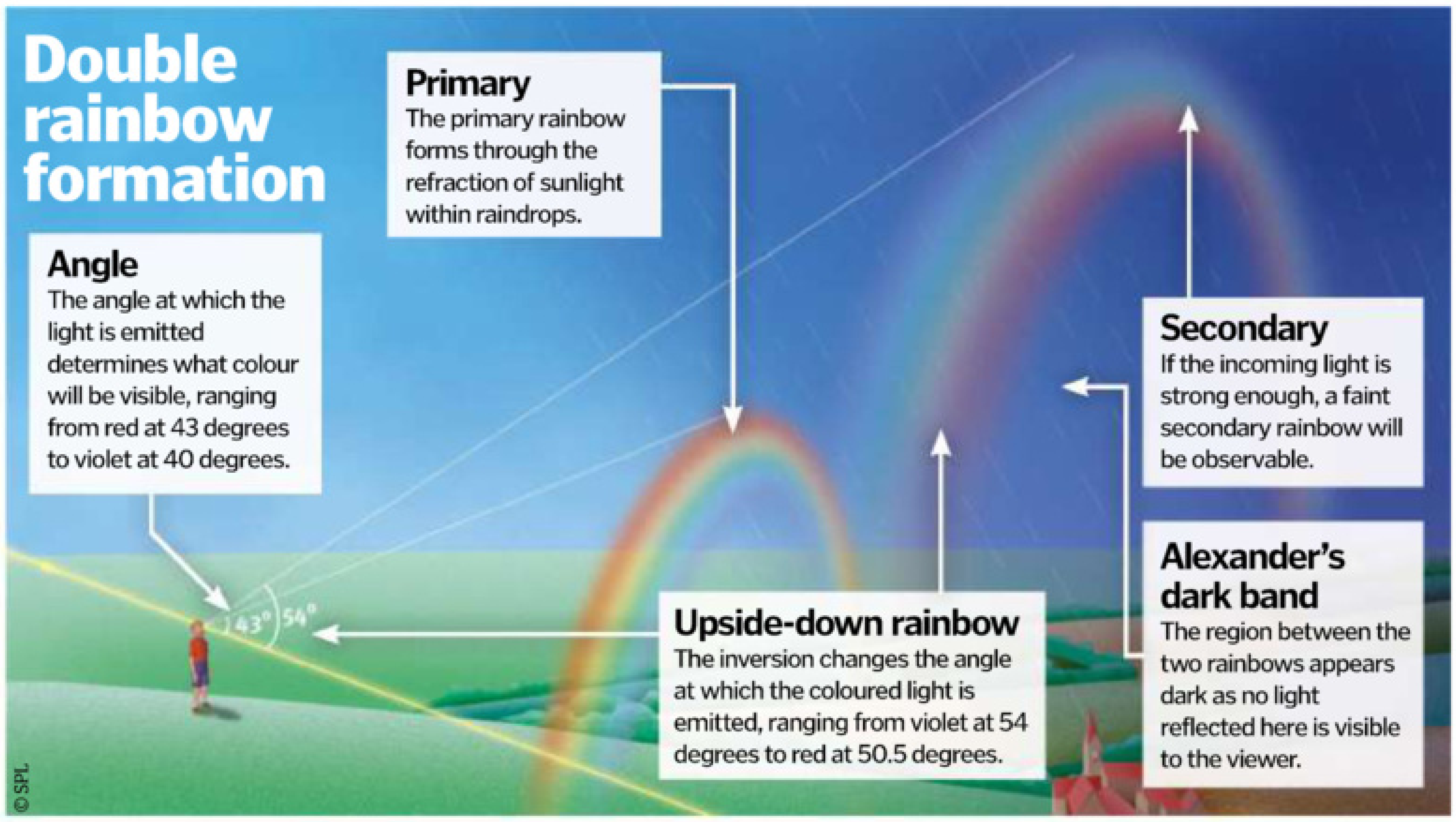
What causes this colourful meteorological phenomenon?

Regular rainbows occur when moisture in the air – commonly rain, but also mist or spray such as that from a waterfall – refracts sunlight in such a way that it is broken up into its constituent colours.

The phenomenon occurs when the Sun is positioned behind you and sunlight passes through the airborne water. The light refracts (bends) inside the droplets and the white light is broken up. Each colour has a different wavelength so, depending on the angle of refraction, a different colour of light will be reflected outwards; the result of this process is what we observe when we see a rainbow.

Every rainbow is accompanied by another, secondary rainbow, but it's usually too dim to see. This double rainbow effect is due to the continued reflection of light inside each water drop. Sunlight is actually reflected twice inside a drop: once to produce the primary rainbow and a second time at the back of the drop. This second reflection inverts the light but undergoes the same refraction, so exits in the same way as before – though upside down.

This second reflection reduces the intensity of the sunlight, but it also produces a second inverted rainbow, creating a double arc of multicoloured light in the sky. Interestingly, sunlight can reflect many more times inside a water drop so many more rainbows (three, four or even more) can be produced, but the incoming light is rarely strong enough for these to be visible by the naked eye.



Double rainbow formation

Primary
The primary rainbow forms through the refraction of sunlight within raindrops.

Angle
The angle at which the light is emitted determines what colour will be visible, ranging from red at 43 degrees to violet at 40 degrees.

Secondary
If the incoming light is strong enough, a faint secondary rainbow will be observable.

Alexander's dark band
The region between the two rainbows appears dark as no light reflected here is visible to the viewer.

Upside-down rainbow
The inversion changes the angle at which the coloured light is emitted, ranging from violet at 54 degrees to red at 50.5 degrees.

© SPL

A double rainbow above the Krimml Waterfalls in Austria

> "Every rainbow is accompanied by another secondary one, but it's usually too dim to see"

Why is snow white?

Have you ever wondered how snow is white? It's all down to the refracted light

To answer this question there are two things which need to be considered – colour theory and refraction. Refraction is the change in direction of light as it goes from one material to another. It is due to a slight change in speed of the light and it explains why straws look bent in water. When light enters snow, it refracts. This is because snow is made from lots of ice crystals tightly packed together, the important fact here being that these crystals are translucent (light can pass through but not in a direct path – it changes direction).
Additive colour mixing tells us that if we combine all of the frequencies of colours we get white light. When light falls on snow it is composed of a mixture of different frequencies which all refract slightly differently as they enter the ice crystals. Eventually due to refraction, the light leaves the surface of the snow in all directions and hits our eyes. This light is composed of a mixture of frequencies which our eyes detect as white light.

HEAD2HEAD

HIGHEST CLOUDS

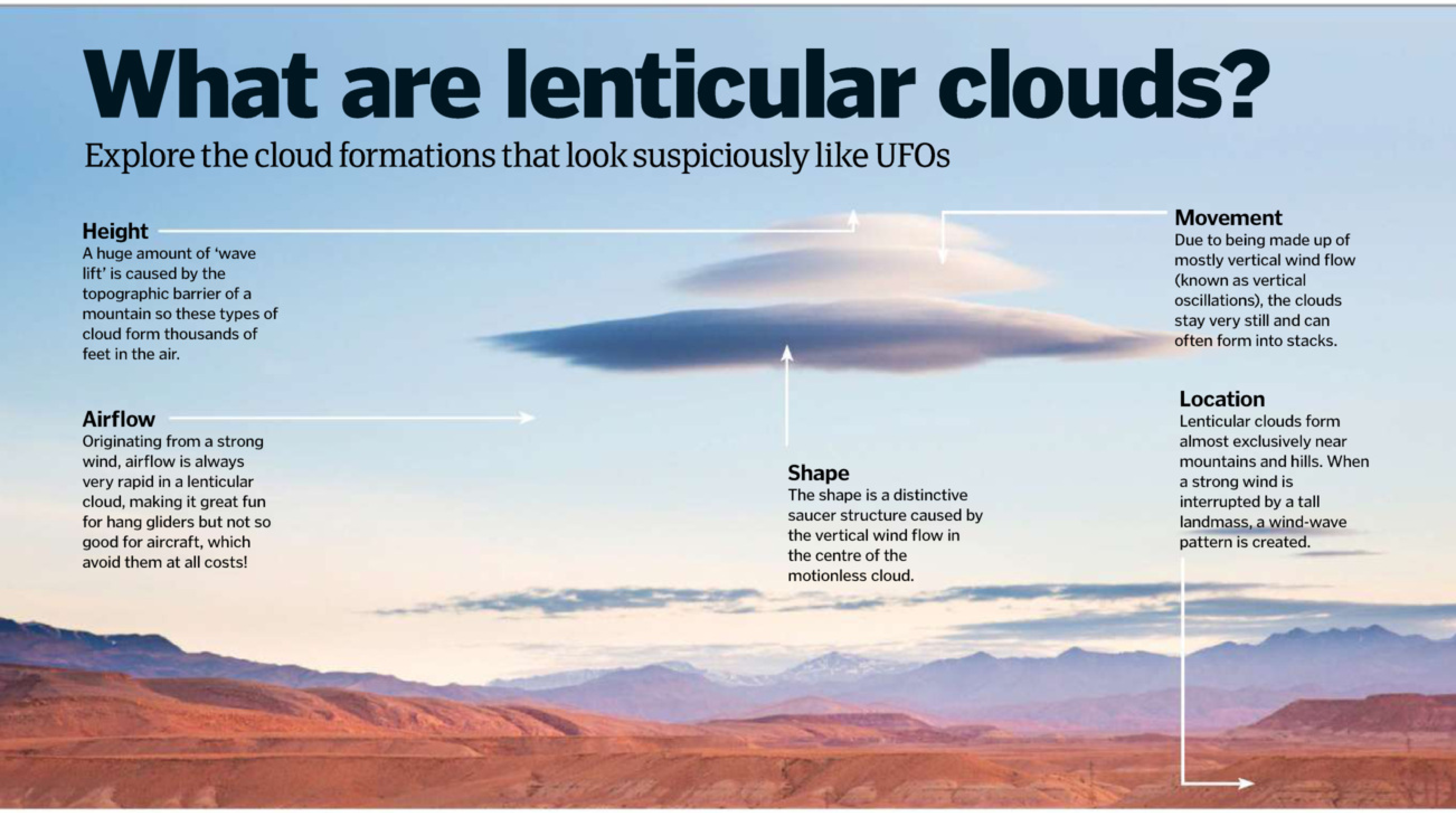
Cumulus
These small clouds that look like bits of cotton wool don't ever soar above 1,980m (6,500ft) in the sky, which is still higher than some others.

Altostratus
A blue or greyish cloud formation, altostratus clouds are found at a height of between 2,130m (7,000ft) to 5,500m (18,000ft).

Cirrus
Found at altitudes of up to a lofty 12,200m (40,000ft), cirrus clouds take on and reflect the red colour of the sunset you see at dusk.

What are lenticular clouds?

Explore the cloud formations that look suspiciously like UFOs



Height
A huge amount of 'wave lift' is caused by the topographic barrier of a mountain so these types of cloud form thousands of feet in the air.

Airflow
Originating from a strong wind, airflow is always very rapid in a lenticular cloud, making it great fun for hang gliders but not so good for aircraft, which avoid them at all costs!

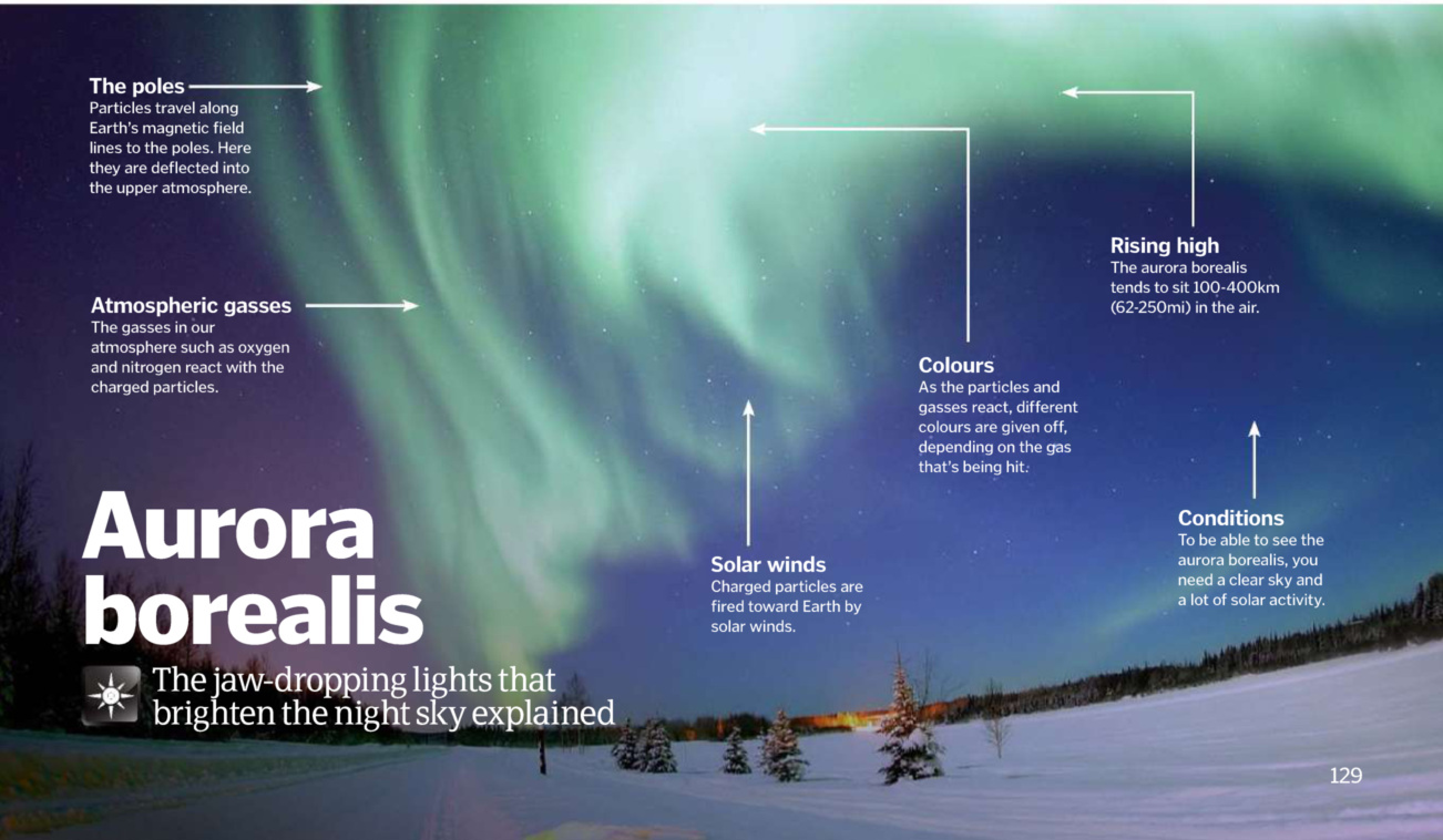
Shape
The shape is a distinctive saucer structure caused by the vertical wind flow in the centre of the motionless cloud.

Movement
Due to being made up of mostly vertical wind flow (known as vertical oscillations), the clouds stay very still and can often form into stacks.

Location
Lenticular clouds form almost exclusively near mountains and hills. When a strong wind is interrupted by a tall landmass, a wind-wave pattern is created.

Aurora borealis

The jaw-dropping lights that brighten the night sky explained



The poles
Particles travel along Earth's magnetic field lines to the poles. Here they are deflected into the upper atmosphere.

Atmospheric gasses
The gasses in our atmosphere such as oxygen and nitrogen react with the charged particles.

Solar winds
Charged particles are fired toward Earth by solar winds.

Colours
As the particles and gasses react, different colours are given off, depending on the gas that's being hit.

Rising high
The aurora borealis tends to sit 100-400km (62-250mi) in the air.

Conditions
To be able to see the aurora borealis, you need a clear sky and a lot of solar activity.

Essential to organic life, nitrogen makes up most of the Earth's atmosphere. It is a major component in the building of protein in cells, and is vital in the production of amino acids. However, we cannot obtain nitrogen, as a gas, directly from the soil or air without it being combined with another element, and so it must go through a series of four natural chemical reactions – nitrogen fixation, nitrification, denitrification and decay – known as the nitrogen cycle. Understanding the stages of the nitrogen cycle can seem complicated because nitrogen can exist in several different forms. While food-making organisms get the nitrogen they need from nitrogen fixation and nitrification, animals and humans don't make their own food and so must eat plants or animals that eat plants to get their fill.

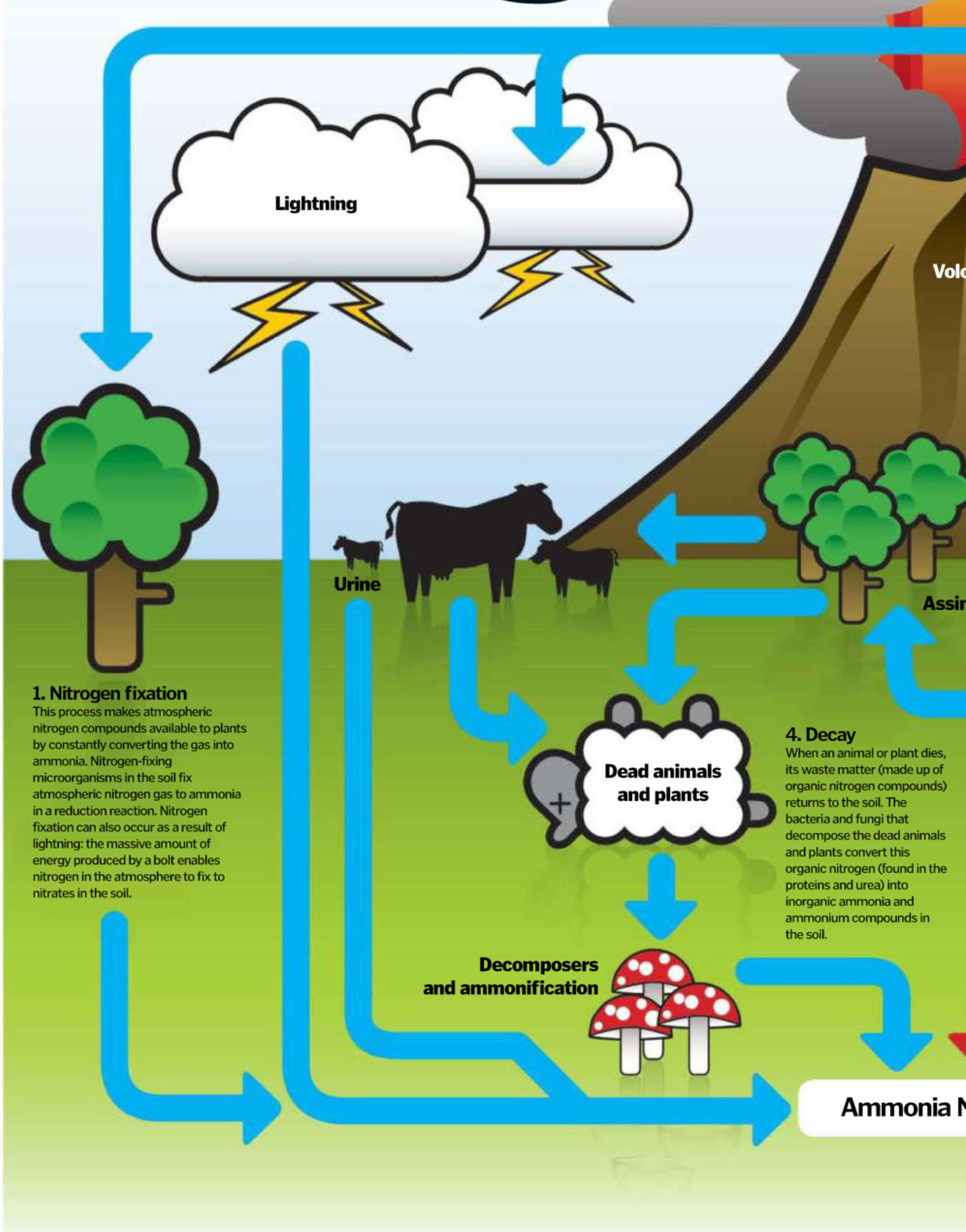
First, let's take nitrogen fixation. Although there is a vast amount of nitrogen gas in the atmosphere, it must be fixed – or put into a biologically useful compound – for living organisms like us to be able to use it. Only then can it start to move through the ecosystem. Fixation starts off when bacteria convert nitrogen gas into ammonia in the soil. Special plants known as legumes also have certain bacteria in their roots that make this possible.

Once in the soil, the nitrogen becomes biologically accessible, and nitrification is the process that takes nitrogen fixation one step further. Specialised bacteria use oxidation to convert ammonia into nitrite, and nitrite into nitrate, which plants can incorporate into their tissues.

During what's known as denitrification, plants take nitrogen from waterlogged soil by absorbing nitrates and ammonium ions, turning them into organic compounds. Nitrogen compounds are also returned to the soil through animal waste and decaying plants and animals.

Although the most abundant form of nitrogen is obviously the air around us, the processes through which nitrogen gets into the rest of our ecosystem are essential for the circle of life.

Nitrogen



1. Nitrogen fixation

This process makes atmospheric nitrogen compounds available to plants by constantly converting the gas into ammonia. Nitrogen-fixing microorganisms in the soil fix atmospheric nitrogen gas to ammonia in a reduction reaction. Nitrogen fixation can also occur as a result of lightning: the massive amount of energy produced by a bolt enables nitrogen in the atmosphere to fix to nitrates in the soil.

4. Decay

When an animal or plant dies, its waste matter (made up of organic nitrogen compounds) returns to the soil. The bacteria and fungi that decompose the dead animals and plants convert this organic nitrogen (found in the proteins and urea) into inorganic ammonia and ammonium compounds in the soil.

5 TOP FACTS NITROGEN

The invisible element

1 Nitrogen is colourless, odourless and tasteless, and although practically inert at normal temperatures, when altered it can be used for foods, fertilisers and poisons.

Liquid ice

2 When nitrogen is cooled to below -196°C it turns into a liquid that can freeze a substance in seconds. Handy in medicine for transporting blood and transplant organs.

Big bangs

3 Nitrogen is even used in explosives such as TNT. The chemicals used in this kind of nitrogen compound break apart releasing huge quantities of gas.

Breathe easy

4 Nitrogen gas makes up 78.08 per cent of the Earth's atmosphere; the rest is 20.95 per cent oxygen, 0.93 per cent argon, 0.038 per cent CO_2, plus traces of other gases.

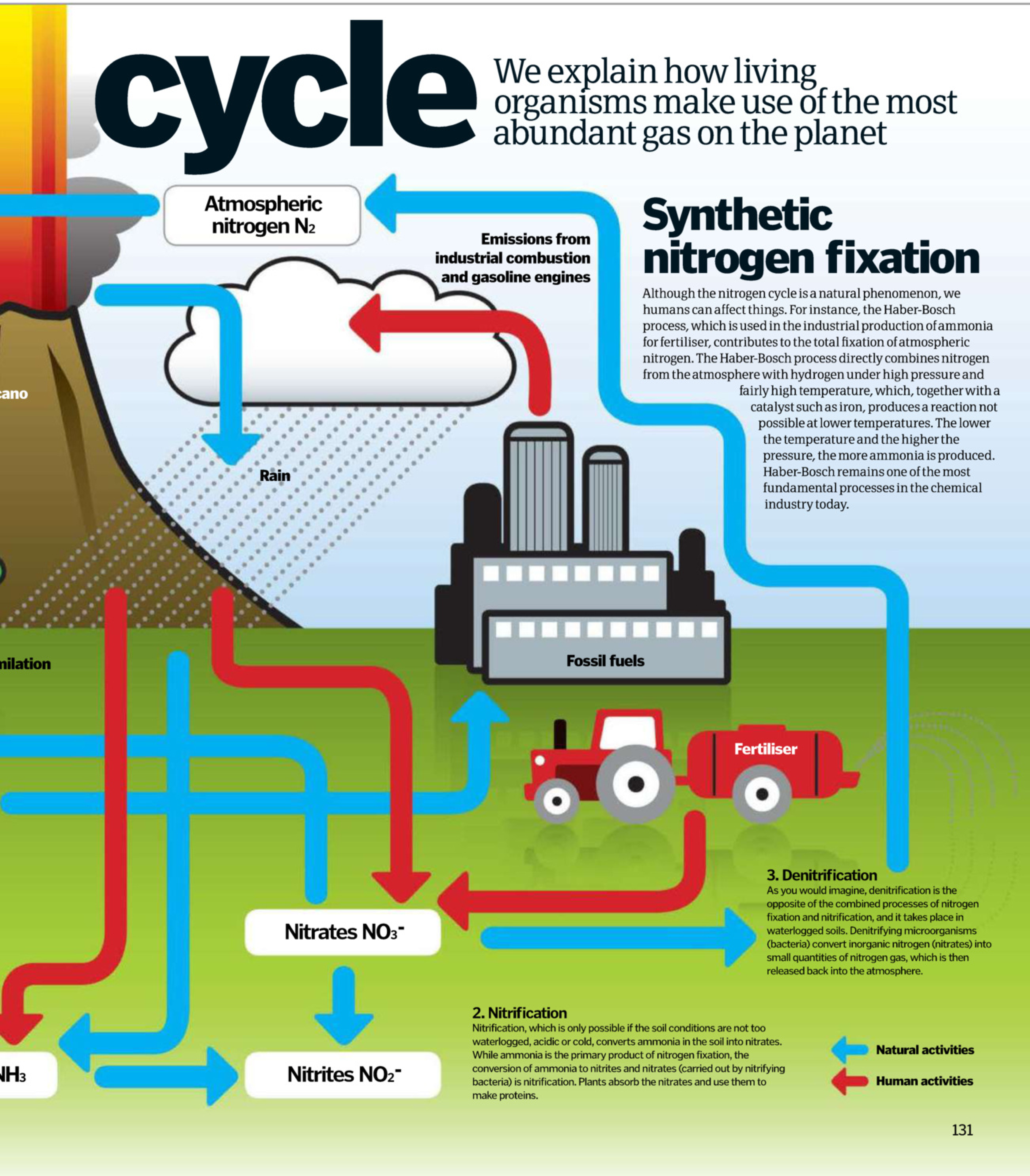
Colourful effects

5 Nitrogen is responsible for the orange-red, blue-green, blue-violet, and deep violet colours that are visible with the aurora borealis (the northern lights).

DID YOU KNOW? *Harvesting plants before they die means soil requires fertilisers containing nitrates or ammonium compounds*

cycle

We explain how living organisms make use of the most abundant gas on the planet



Synthetic nitrogen fixation

Although the nitrogen cycle is a natural phenomenon, we humans can affect things. For instance, the Haber-Bosch process, which is used in the industrial production of ammonia for fertiliser, contributes to the total fixation of atmospheric nitrogen. The Haber-Bosch process directly combines nitrogen from the atmosphere with hydrogen under high pressure and fairly high temperature, which, together with a catalyst such as iron, produces a reaction not possible at lower temperatures. The lower the temperature and the higher the pressure, the more ammonia is produced. Haber-Bosch remains one of the most fundamental processes in the chemical industry today.

3. Denitrification

As you would imagine, denitrification is the opposite of the combined processes of nitrogen fixation and nitrification, and it takes place in waterlogged soils. Denitrifying microorganisms (bacteria) convert inorganic nitrogen (nitrates) into small quantities of nitrogen gas, which is then released back into the atmosphere.

2. Nitrification

Nitrification, which is only possible if the soil conditions are not too waterlogged, acidic or cold, converts ammonia in the soil into nitrates. While ammonia is the primary product of nitrogen fixation, the conversion of ammonia to nitrites and nitrates (carried out by nitrifying bacteria) is nitrification. Plants absorb the nitrates and use them to make proteins.

Influencing cloud formation

We explore elemental factors influencing varying cloud types

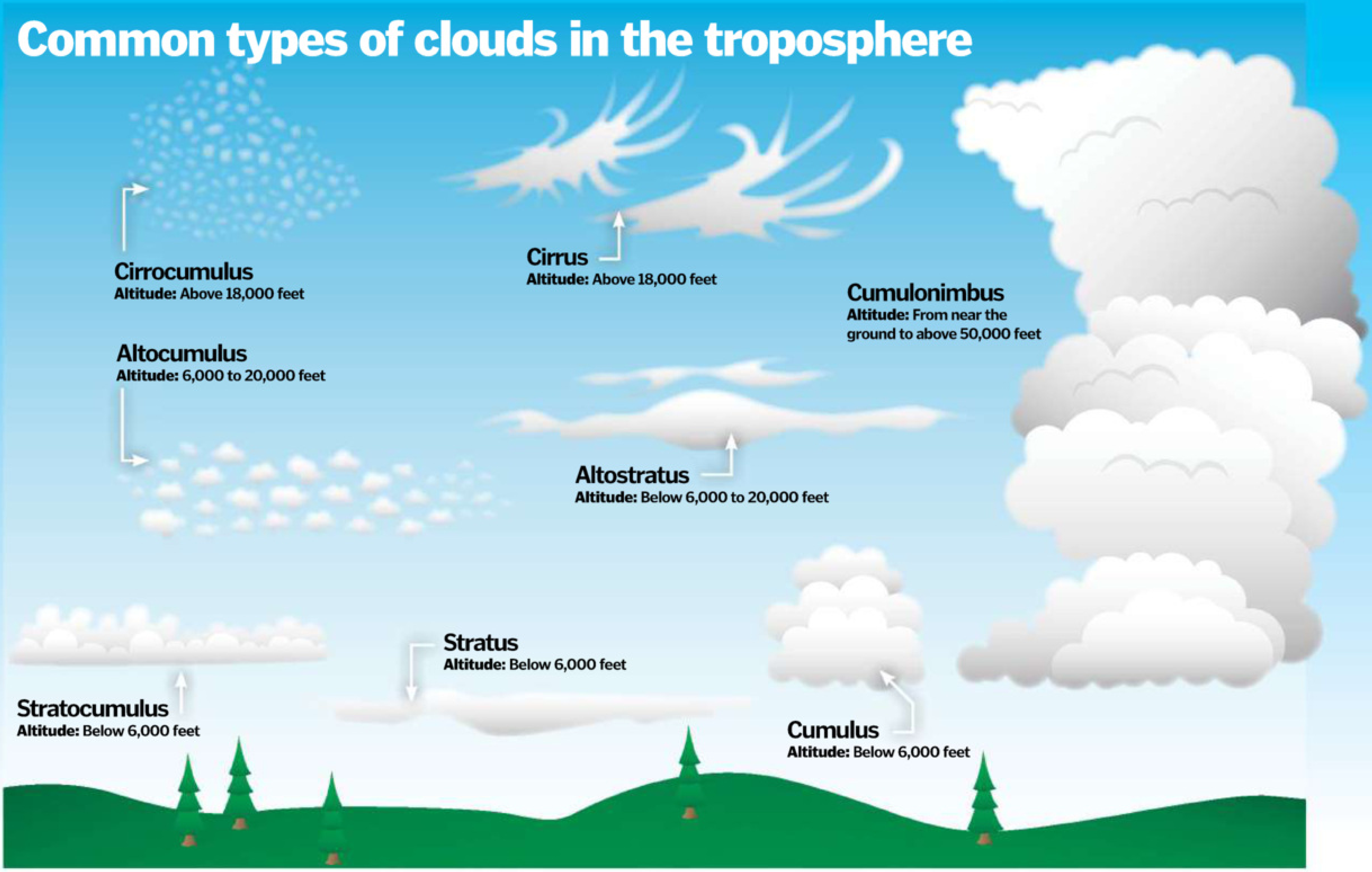
Look up into the sky above and you will notice that clouds constantly shift in shape and size. This is due to there being numerous common types of cloud formation, with each performing a natural role, which is determined by external factors such as altitude, condensation and disposition. These include stratus, cumulus, stratocumulus, altocumulus, cirrus, cirrocumulus and cumulonimbus.

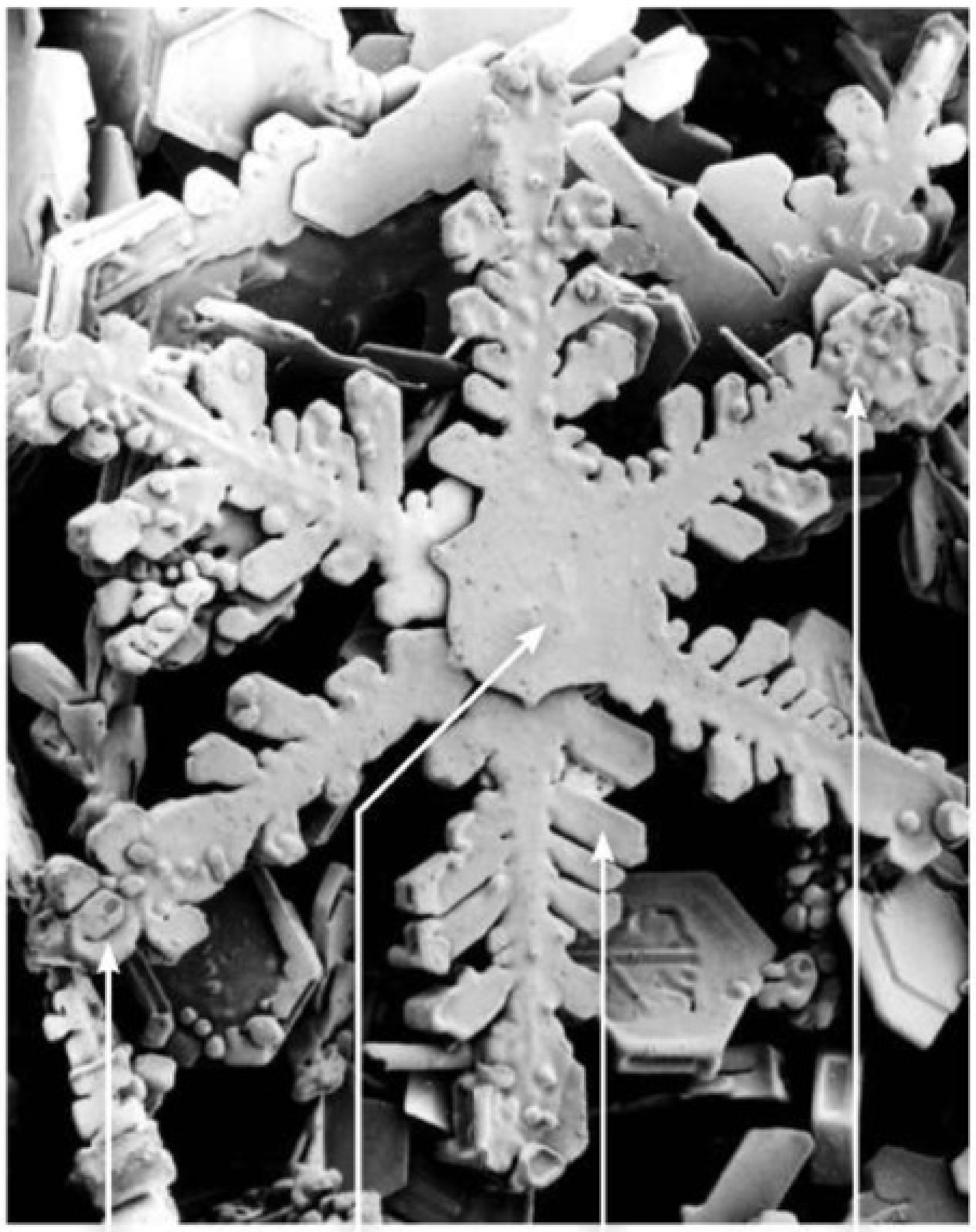
Most cloud formations are produced in environments that are saturated, or where relative humidity is at 100 per cent. Varying mechanisms can activate this process. For example orographic uplift, which occurs as air is forced up due to the physical presence of elevated landmass. As air rises it cools as a result of adiabatic expansion, at a rate of approximately ten degrees Celsius per every 1,000 metres, until saturation occurs. Stratus clouds, for example, form when minimal upward vertical air currents lift a thin layer of air high, which is enough to initiate the condensation of excess water vapour.

Altocumulus clouds are part of the middle order of formations, appearing greyish with dark patchy areas. Often these clouds precede a cold front, and on a warm humid morning indicate approaching thunderstorm activity. Altocumulus clouds are often produced due to turbulent updrafts of air, uplifted by terrain barriers such as mountains, composed of super-cooled water, below freezing, which has not yet crystallised around a condensation nucleus.

There are several cloud formations at high altitude. Most notable are cumulonimbus, which form if cumulus congestus clouds continue to grow vertically. Ranging from near ground level up to 50,000 feet, this formation releases enormous amounts of energy by condensated water vapour. Lightning, hail and violent tornadoes are associated with cumulonimbus clouds. During the formation, condensation carries droplets up and down several times before being released and combining to form raindrops. In larger specimens up-currents become extremely severe, splitting raindrops and ice crystals, before re-combining and falling to the ground. This contributes to a build up of electrical charges and therefore the occurrence of lightning.

Common types of clouds in the troposphere


Cirrocumulus
Altitude: Above 18,000 feet
Cirrus
Altitude: Above 18,000 feet
Cumulonimbus
Altitude: From near the ground to above 50,000 feet
Altocumulus
Altitude: 6,000 to 20,000 feet
Altostratus
Altitude: Below 6,000 to 20,000 feet
Stratus
Altitude: Below 6,000 feet
Stratocumulus
Altitude: Below 6,000 feet
Cumulus
Altitude: Below 6,000 feet



Shape The unique shape of a snowflake is dependent on temperature and moisture.

Main facet Water vapour freezes on to a molecule of ice, creating a flat surface called a facet.

Main branches Each snowflake develops six branches from the central hexagonal facet.

Symmetry Each branch extends outwards at exactly the same rate as all the others.

Snowflakes

How are these beautiful crystals of ice formed?

The formation of a snowflake begins when a microscopic cloud droplet freezes as a tiny ice particle. Water vapour that condenses on its surface causes the ice to develop flat, polished surfaces, known as facets, which continue to grow into a hexagonal prism shape. At each corner of the hexagon shape, new branches extend outwards each at the same rate. All snowflakes have six sides and can be either prism-shaped, plate-shaped or star-shaped.

As the snowflake moves around within the cloud, it encounters a variety of temperatures that change the growth behaviour of each flake, causing the six branches of the crystal to grow in exactly the same way, creating six-way symmetry and a unique flake every time.

The first person to photograph a snowflake was American Wilson Bentley. Bentley took his first snowflake snap in 1885, using a bellows camera and a compound microscope, and went on to assemble a large collection of beautiful snow crystal images.

Here's one I made earlier

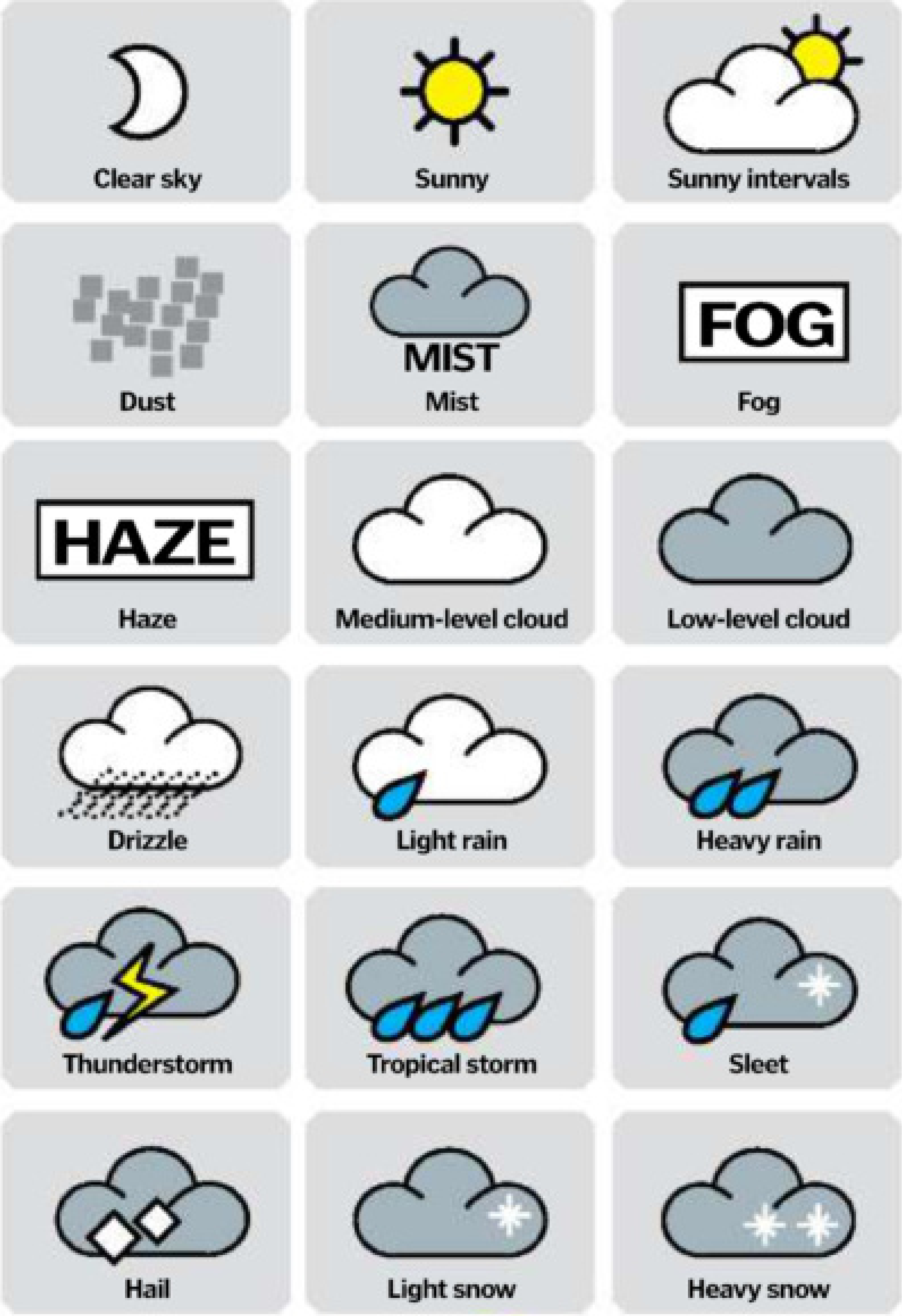
Weather symbols

How to read and understand the symbols on a weather map

Weather forecast centres around the world are constantly analysing atmospheric conditions on Earth. The public are then supplied with this information in the form of pictographic maps detailing precipitation, cloud, wind speed/direction, temperature, and frontal systems.

Types of weather

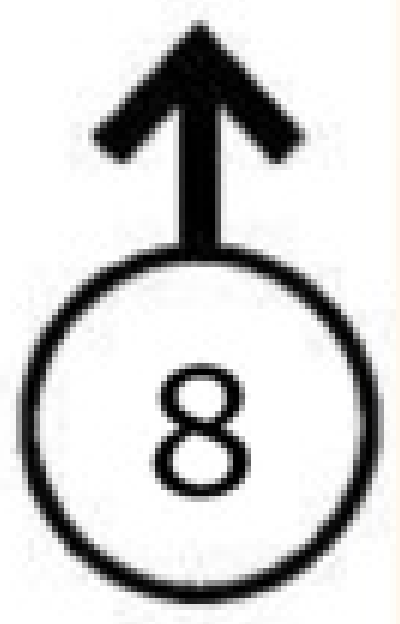
The other symbols found on a weather map include the various types of weather. The following classification symbols are based on those the MET Office uses. There are additional symbols for day and night variations…



Temperature ⑫

Temperature is shown as a figure (measured in degrees Fahrenheit or degrees Celsius) depicted either by a number in a circle/square, or as an isotherm, which is a line linking points of equal temperature.

Wind



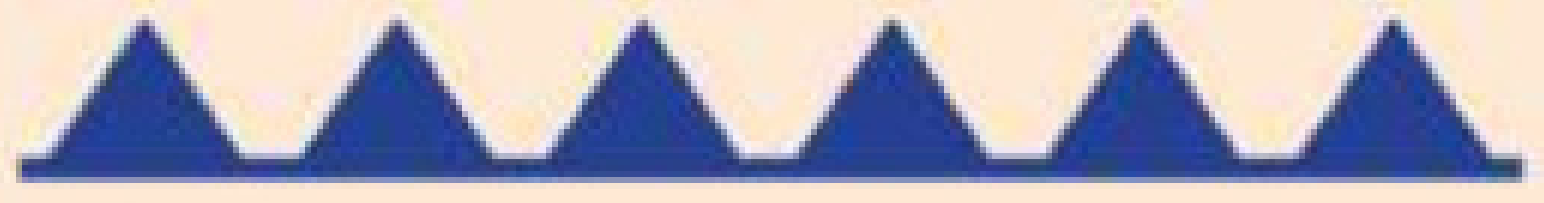
Wind also features a figure that shows wind speed in miles per hour. This number is accompanied by an arrow to indicate which direction the wind is travelling.

Pressure —— 982 ——

Atmospheric pressure is shown in the form of isobars, which are lines of equal mean sea-level pressure. When there is a difference in air pressure, air is accelerated from high to low pressure, causing windy conditions.

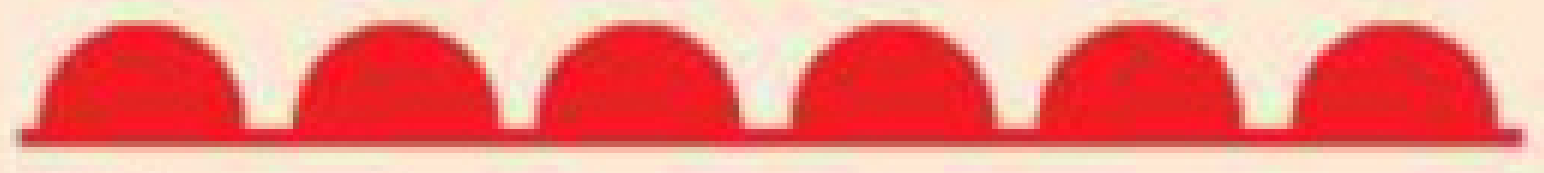
Fronts

A weather front is the line on a map dividing two air masses of different densities. Here conditions will be unsettled. The symbols for fronts are arranged on lines consisting of semicircles, triangles or a mixture of the two.



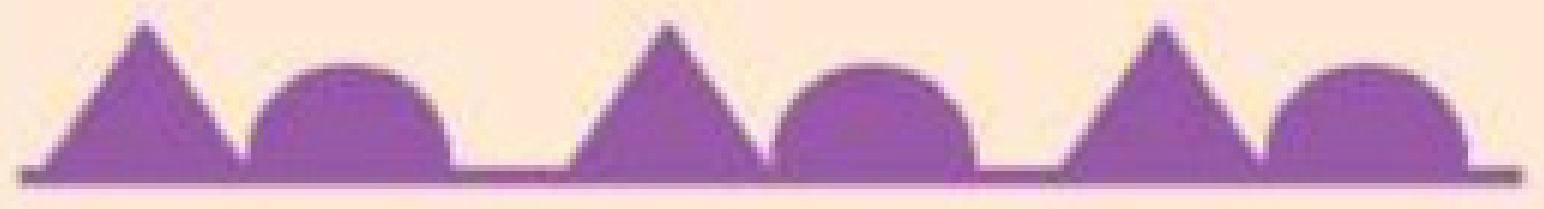
Cold front

Associated with brief episodes of severe weather, and identified by a blue line with triangles that point in the direction of movement, a cold front marks the leading edge of an advancing mass of cold air. Because cold air is denser, it pushes the warmer air up where it condenses into clouds and precipitation. Dense cold air also travels faster than warm.



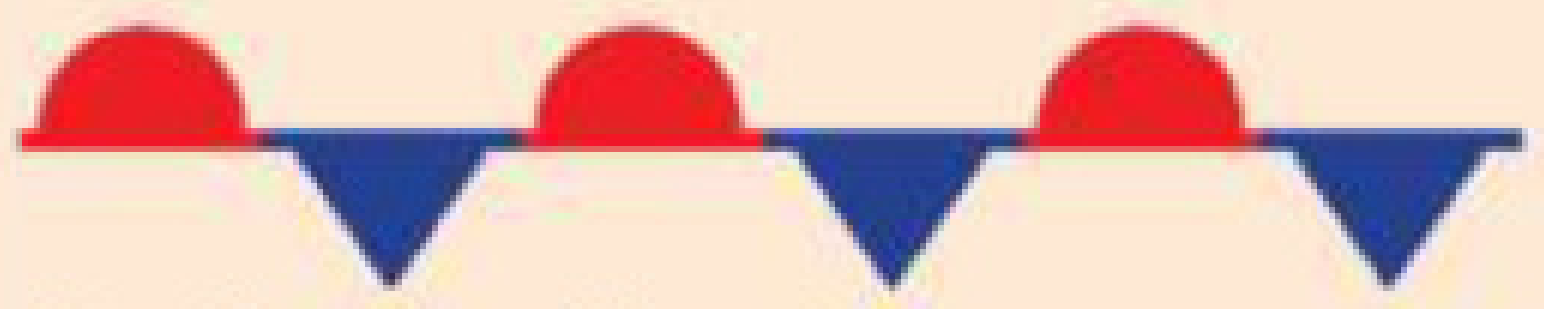
Warm front

Slower-moving warm fronts are marked on weather maps as a red line with semicircles that point in the direction of movement. These represent the leading edge of an advancing mass of warm, moist air, bringing with it cloud, precipitation and warm temperatures.



Occluded front

This purple line of alternating triangles and semicircles denotes an occluded front, or occlusion, which forms when the faster-moving cold front catches up with the warm front, forcing the less-dense warm air up above the surface.



Stationary front

These stationary, or slow-moving fronts represent the boundary between two air masses neither of which has the ability to replace the other. Stationary fronts are depicted by an alternating line of red semicircles and blue triangles pointing in opposite directions. Clouds and prolonged precipitation are associated with these fronts.

HOW IT WORKS

THE WEATHER & US

How the human race interacts with weather

© Alamy

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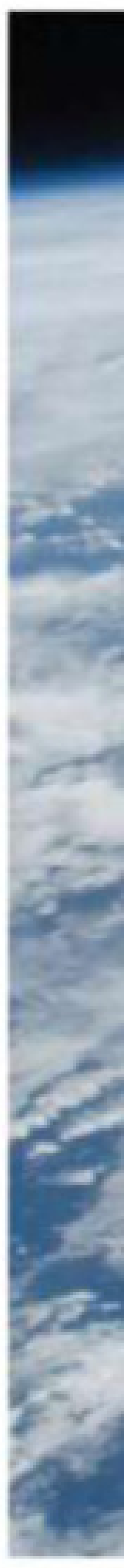
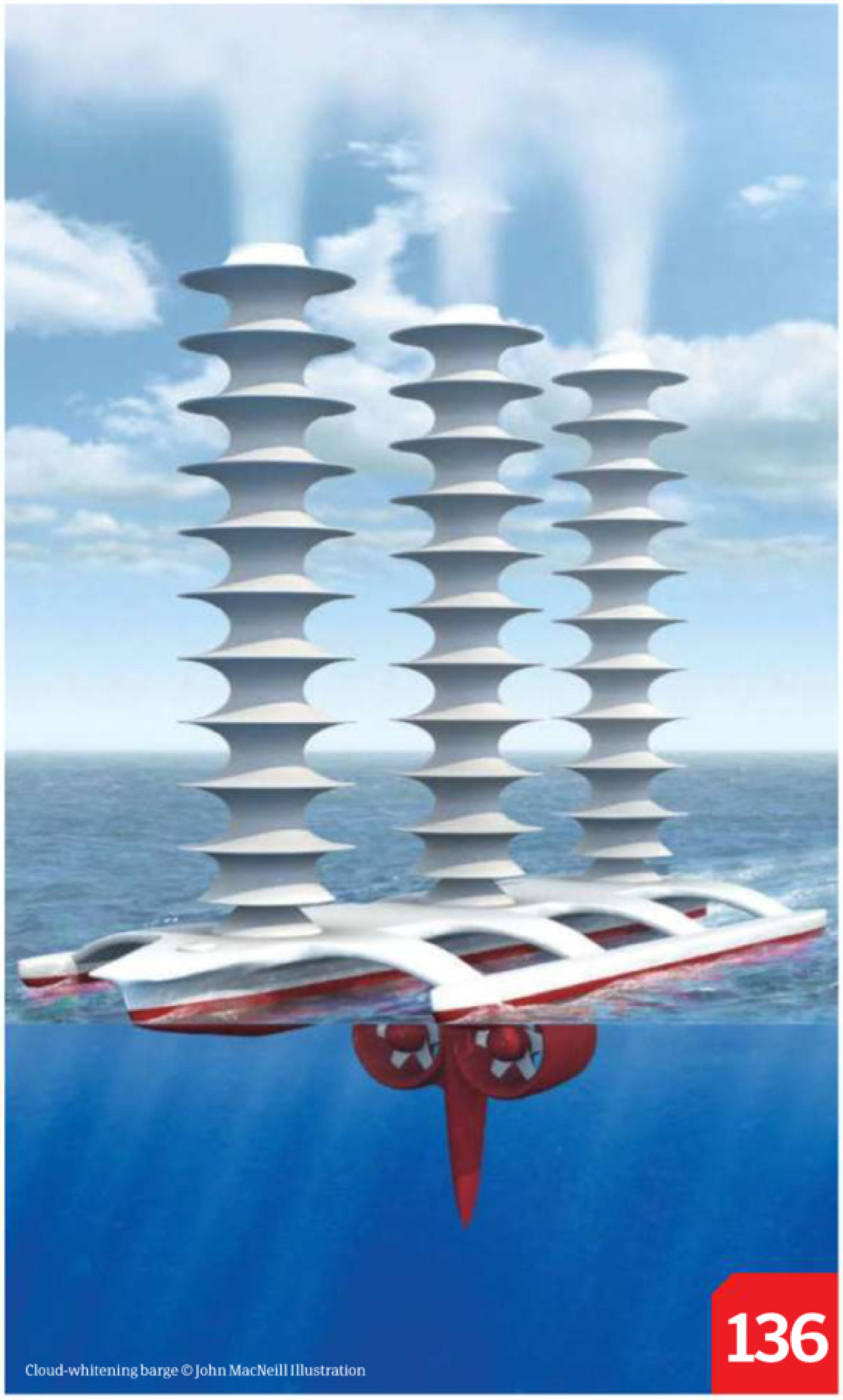




Cloud-whitening barge © John MacNeill Illustration

CONTROLLING THE WEATHER

DISCOVER HOW WE MAKE RAIN AND THE AMBITIOUS PLANS BEING HATCHED TO TACKLE CLIMATE CHANGE

Superhero Storm in the *X-Men* comics can conjure rain, end droughts and create hurricanes with the power of her mind. Now, scientists and meteorological technology are opening more and more opportunities for us mere mortals to manipulate weather and Earth's climate.

In 2009, Chinese meteorologists from the Beijing Weather Modification Office claimed to be responsible for the city's earliest snowfall since 1987. Around 16 million tons of snow reportedly fell over drought-afflicted northern China after workers fired rockets carrying pellets of silver iodide into heavy clouds.

The rockets were cloud seeding, a process invented in the late-Forties. Supporters claim it can reduce hail damage, increase rainfall and disperse fog among other things. There are cloud-seeding projects in at least 20 countries worldwide, from Israel to Australia; in 2003, in the US alone, ten states were conducting at least 66 cloud-seeding programmes. In China, around 32,000-35,000 people are employed in the weather modification industry.

The big question in cloud seeding is: how effective is it? A 2003 US National Academies report concluded there was no concrete scientific proof it worked. According to Professor Michael Garstang from the University of Virginia, who chaired the report, the situation hasn't changed much since; there remains "a lack of definitive evidence," he says.

Even cloud-seeding supporters admit it doesn't currently lead to a huge rise in rain and snowfall. "It doesn't increase precipitation by 50 per cent in most cases," says Bruce Boe from Weather Modification Inc, a private weather control company based in North Dakota, USA.

US enthusiasm for weather modification research waned in the late-20th century, with funding falling to less than five per cent of its Seventies peak. But there are signs of fresh interest in the field. The US National Science Foundation (NSF) is funding a cloud-seeding project in the Wyoming mountains, operated by Weather Modification Inc. New technology, such as advanced computer models and radar instruments that can see inside clouds is driving the resurgence of interest, says Boe: "We're bringing a lot of new tools to bear on the question. These tools weren't available before and they're starting to bear fruit."

The Wyoming project, launched in 2005, uses aircraft-mounted radar and ground-based

5 TOP FACTS

MYTHS BUSTED

Geoengineering is ready

1 Today's geoengineering ideas are untested or small-scale experiments. Cooling Earth by one degree Celsius would require a minimum five years of military-scale effort.

One tech is enough

2 No single 'magic technology' can cool the Earth. Future geoengineers might use many fixes, like reflective buildings, a space-based deflector and encouraging reforestation.

It solves climate change

3 Geoengineering doesn't stop greenhouse gas emissions – the root cause of man-made climate change. It's a 'plaster', pausing harmful warming to give us time to cut emissions.

We can't create rain

4 There's emerging evidence that cloud seeding *can* make rain. An Australian project in 2005-2009 found that rainfall increased in suitable clouds by an average 14 per cent.

It's all a conspiracy

5 There's no scientific evidence behind claims that HAARP, a US facility studying Earth's ionosphere, is a secret conspiracy for creating hurricanes as weapons.

DID YOU KNOW? *A global survey in 2010 found 72 per cent of us supported research into reflecting sunlight to cool the planet*

instruments. It tests the effectiveness of seeding winter orographic clouds – which are cold clouds formed when air rises over mountains – with silver iodide.

"In the mountains of the American West, these types of storms are the main target for cloud seeding. Often the clouds are not efficient at generating snow, so cloud seeding is used to enhance snow production," says Dan Breed from the US National Center for Atmospheric Research (NCAR), who is evaluating the project.

Another aim of the experiment is to increase snowfall by perhaps ten per cent a year, building up the winter snowpack so it's available for use. The extra water running off the mountains each spring would be worth an estimated £1.5-3 million ($2.4-$4.9 million).

Cloud seeding affects the weather in a local region, but there are other technologies being devised to alter climate on a much bigger scale. Space mirrors and giant floating hosepipes might sound far-fetched, but they're two proposals for geoengineering. Geoengineering is deliberate global modification of Earth's climate to counter man-made climate change.

Geoengineering may sound impossible, but serious scientists are investigating how it might cool down the planet. In the last few years, billionaire Bill Gates reportedly donated £2.8 million ($4.5 million) to geoengineering research, and the UN IPCC report, a summary of what most scientists agree we know about climate change, mentioned geoengineering for the first time this year.

Geoengineering is essentially 'Plan B' in case we reduce greenhouse gas emissions 'too little, too late' to avoid dangerous climate change, argues a 2009 report by the UK's Royal Society. A temperature rise of just two degrees Celsius (3.6 degrees Fahrenheit) could melt the Greenland ice sheet and cause a long-term sea level rise of seven metres (23 feet). That's enough water to submerge both London and Los Angeles.

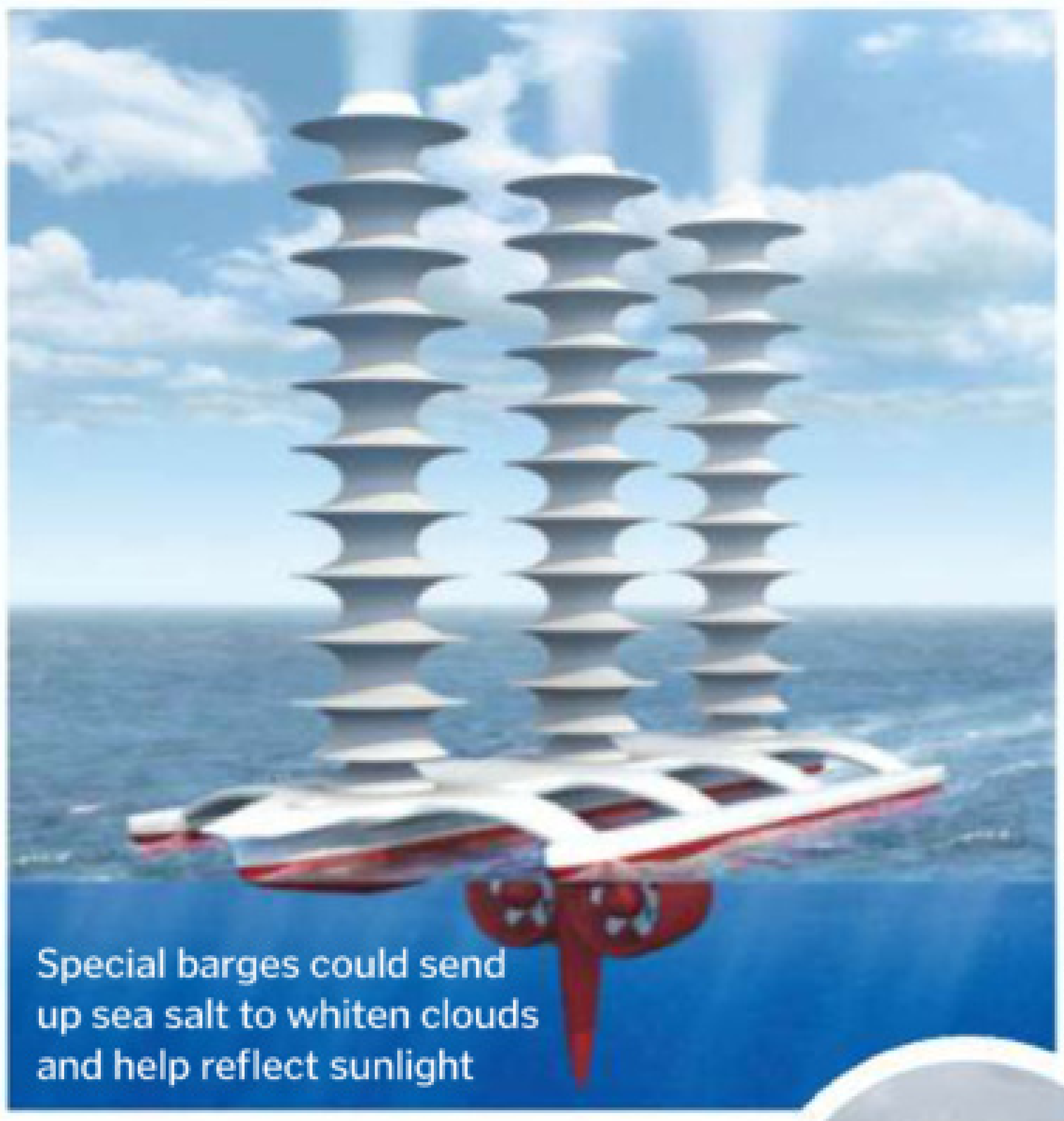
To avoid this wide-scale warming, we'd need to cut global carbon dioxide emissions by 50 per cent of 1990 levels by 2050, according to the Royal Society. Yet emissions are still rising – by 1.4 per cent during 2012. Even if we cut carbon emissions today, temperatures will continue rising for decades. The climate system is like an oil tanker – ie slow to turn around.

Dr Hugh Hunt is an engineer from Cambridge University working on SPICE (Stratospheric Particle Injection for Climate Engineering) – a UK government-funded geoengineering research project: "We don't know what the scale of unabated climate change will be," he says. "You've got to think in advance what emergency measures you might need, and then hope you won't need them."

There are two types of geoengineering. Solar radiation management (SRM) cools the Earth by reflecting the Sun's heat back into space, while carbon dioxide removal (CDR) scrubs CO_2 – the primary greenhouse gas causing man-made climate change – from the atmosphere.

Examples of SRM include space mirrors, injecting sulphate aerosols into the atmosphere through giant hosepipes and painting urban roofs white. One idea uses cloud seeding to make clouds more reflective. Fleets of unmanned 3,000-ton barges could sail the oceans, spraying clouds with saltwater. Salt particles should create more water droplets in the clouds, whitening them. Proposals for CDR include fertilising tiny marine plants with iron, growing new forests or fast-growing crops and burying charcoal, all of which lock up CO_2 and remove it from the air. Most geoengineering proposals remain in the lab at this stage. "We can do very little right now because the

Geoengineering plans include ideas for orbiting sunlight reflectors in space



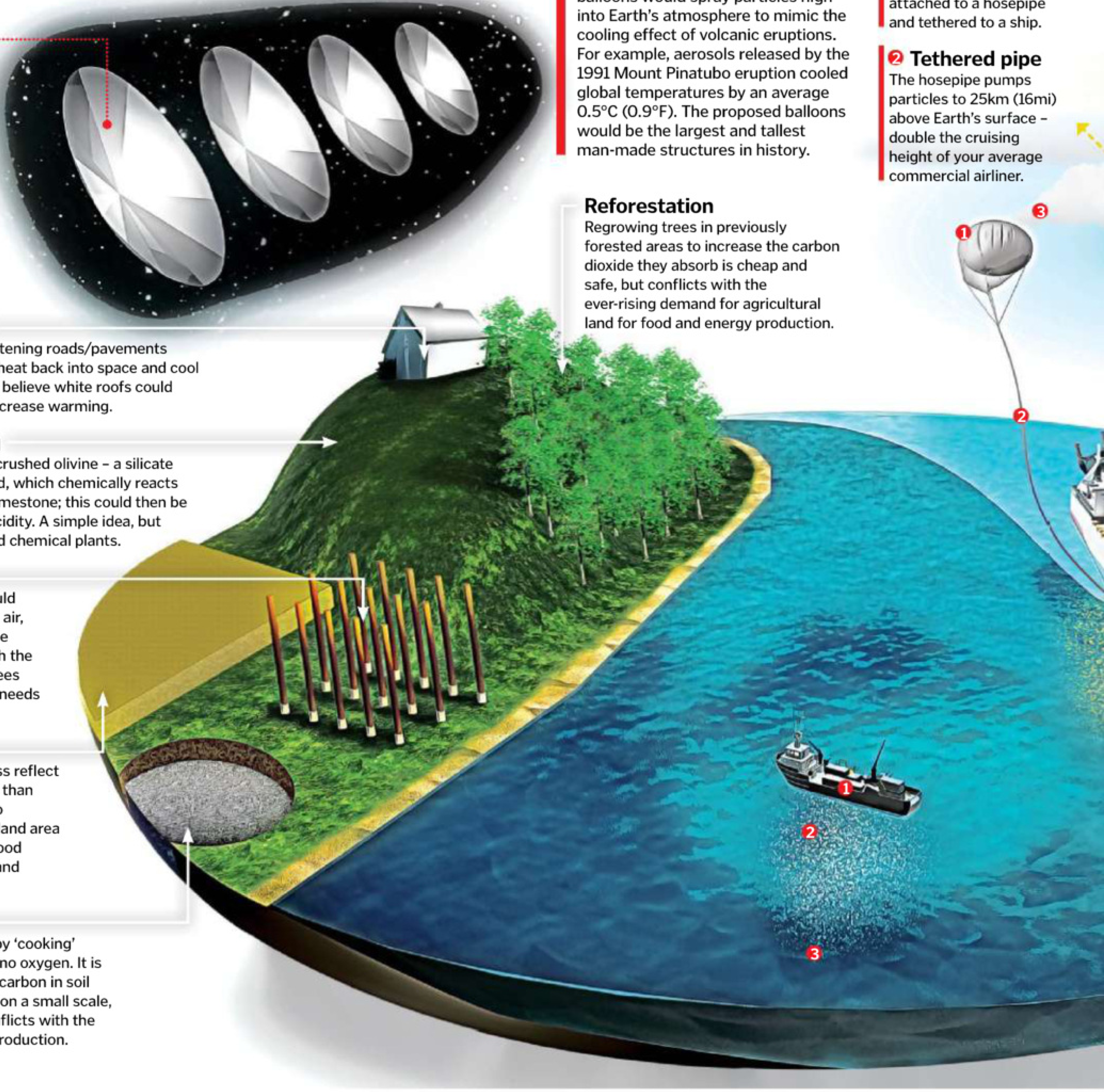
Special barges could send up sea salt to whiten clouds and help reflect sunlight

Cloud-whitening barge © John MacNeill Illustration

New technology has led to a resurgence in cloud-seeding projects

Weather-changing tech in action

Discover the machines and techniques capable of adapting Earth's climate



Space mirrors

A giant sunshade made of tiny mirrors could be put into orbit to cool the Earth. Taking decades and trillions of dollars to deploy, its effect on our weather is unknown and it would not stop the oceans acidifying.

Reflective buildings

Painting roofs white and brightening roads/pavements should help bounce the Sun's heat back into space and cool the Earth, but some scientists believe white roofs could reduce cloud formation and increase warming.

Enhanced weathering

This would involve spreading crushed olivine – a silicate mineral – over agricultural land, which chemically reacts with CO_2 to produce alkaline limestone; this could then be used in the ocean to reduce acidity. A simple idea, but would require huge mining and chemical plants.

Artificial trees

These towering machines would scrub carbon dioxide from the air, turning it into liquid that can be stored in porous rocks beneath the oceans. Millions of artificial trees would be needed and the CO_2 needs storing for millions of years.

Reflective crops

Certain crops, shrubs and grass reflect more sunlight back into space than others. This would be cheap to implement, but needs a huge land area and has unknown effects on food prices, plant growth, disease and drought resistance.

Biochar

Biochar is charcoal produced by 'cooking' plants or manure with little or no oxygen. It is decay-resistant and can store carbon in soil for thousands of years. Useful on a small scale, but growing biochar crops conflicts with the demand for food and biofuel production.

Volcano balloons

Hosepipes attached to giant helium balloons would spray particles high into Earth's atmosphere to mimic the cooling effect of volcanic eruptions. For example, aerosols released by the 1991 Mount Pinatubo eruption cooled global temperatures by an average 0.5°C (0.9°F). The proposed balloons would be the largest and tallest man-made structures in history.

❶ Helium balloon

A helium balloon the size of a football stadium is attached to a hosepipe and tethered to a ship.

❷ Tethered pipe

The hosepipe pumps particles to 25km (16mi) above Earth's surface – double the cruising height of your average commercial airliner.

Reforestation

Regrowing trees in previously forested areas to increase the carbon dioxide they absorb is cheap and safe, but conflicts with the ever-rising demand for agricultural land for food and energy production.

technology hasn't been developed to intervene on a planetary scale," notes Andy Parker.

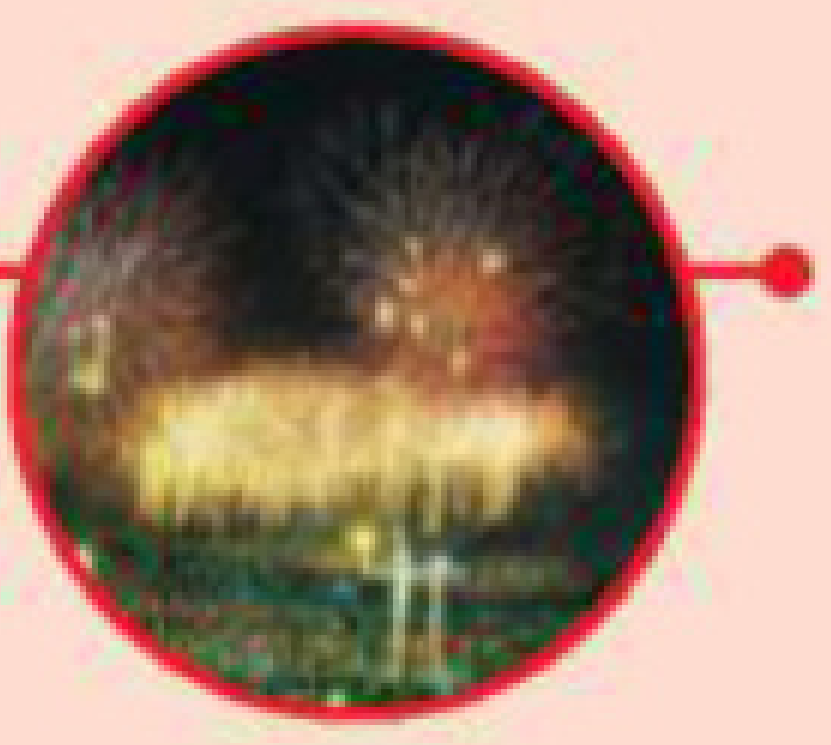
Still, there are a few examples of outdoor field tests. The SPICE project included a plan, later abandoned, to pump water one kilometre (0.6 miles) vertically through a pipe attached to a helium balloon. Its aim was to test the feasibility of squirting sulphate aerosols through a giant hosepipe 20 kilometres (12 miles) above the ground. "We don't know if it's technically possible," continues Dr Hunt. "No one has built a 20-kilometre (12-mile) pipe that goes vertically upwards." Among his unanswered questions are, firstly, can we build and launch a balloon big enough, and secondly, can we build a pipe strong enough?

Other geoengineering proposals rely on pre-existing technology. Fertilising oceans with iron, for example, has already happened on a small scale although not necessarily legally. It needs lots of tanker ships, chemical plants and iron. "There's nothing technically difficult about that," says Professor Andy Ridgwell from Bristol University.

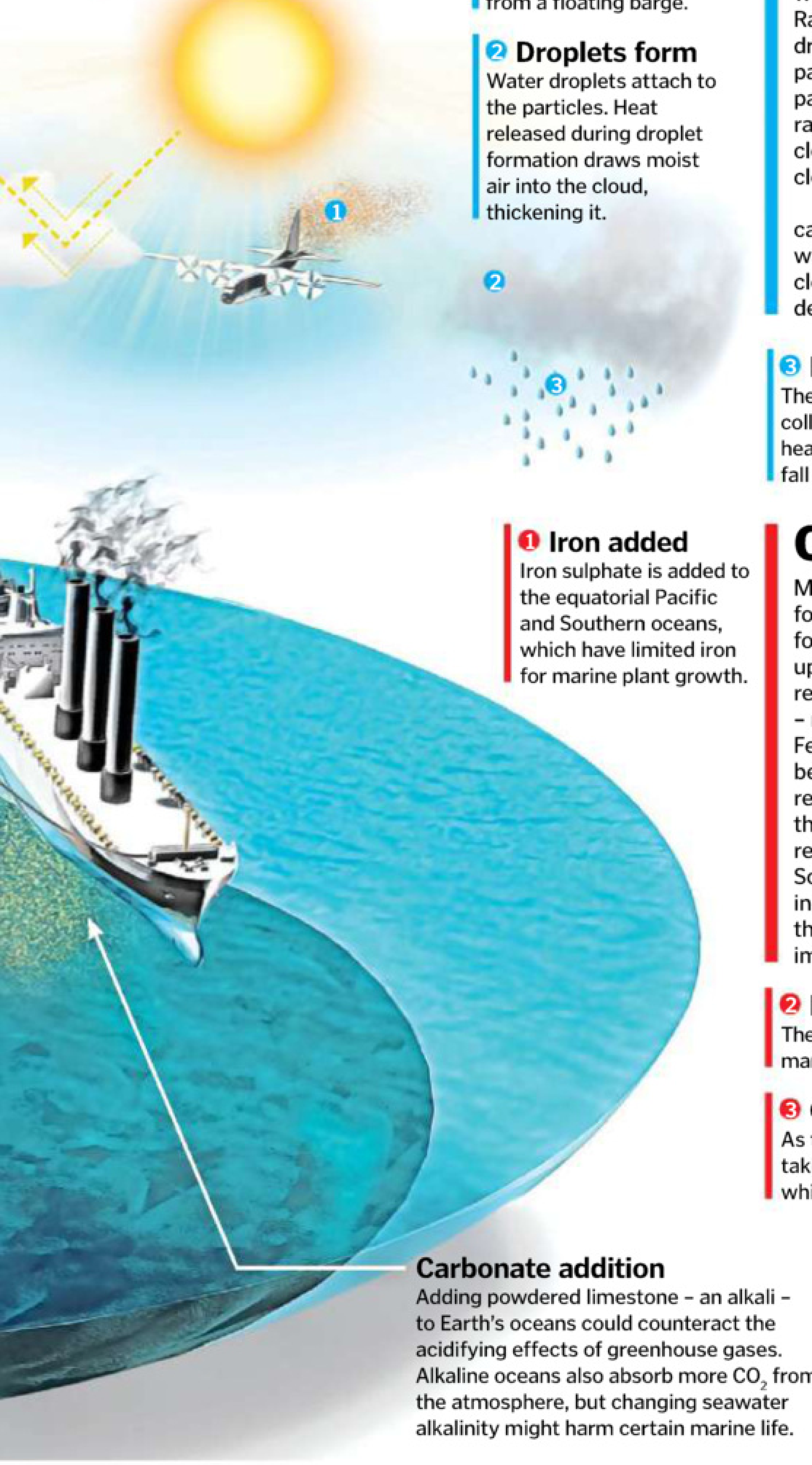
It would take hundreds of years to see results from iron fertilisation and other CDR technologies though. They rely on slow natural processes, such as fertilising tiny marine plants that transport carbon into the deep ocean when they die. "You can't suddenly pull loads of

KEY DATES
MAN-MADE WEATHER

1891	Rainmaker Robert Dyrenforth tries proving noise causes downpours by exploding dynamite kites over Texas.
1946	Vincent Schaefer performs the first cloud-seeding experiments, dropping dry ice pellets into clouds.
1952	34 die in a flood in Lynmouth, England. The UK cloud-seeding Operation Cumulus is blamed.
1967	Operation Popeye, a secret US cloud-seeding project, seeks to deluge enemy troops in Vietnam.
2008	The Chinese government tries to prevent rain at the 2008 Beijing Olympics by launching 1,104 rockets.



DID YOU KNOW? *Global temperatures could rise by more than 1°C by the end of this century, even if we reduce carbon emissions*



❸ Spray of particles
The hosepipe squirts the particles into the stratosphere, scattering solar radiation back into space.

❶ Clouds seeded
Silver iodide or salt is sprayed into clouds from a plane, with a rocket or from a floating barge.

❷ Droplets form
Water droplets attach to the particles. Heat released during droplet formation draws moist air into the cloud, thickening it.

Cloud seeding

Cloud seeding is a technique for man-made rainmaking already used around the world to varying degrees of success. Rainfall naturally occurs when water droplets attach to sand, dust or salt particles. Cloud seeding squirts extra particles into clouds to spawn new raindrops. Salt is used in warm tropical clouds, while silver iodide is added to cold clouds to create extra ice crystals.

Some scientists believe cloud seeding can brighten clouds to counteract climate warming too. The extra particles make the clouds denser, whiter and more reflective, deflecting more sunlight back into space.

❸ Rain falls
The droplets or ice crystals collide, growing bigger and heavier until eventually they fall as precipitation.

❶ Iron added
Iron sulphate is added to the equatorial Pacific and Southern oceans, which have limited iron for marine plant growth.

Ocean fertilisation

Marine plant life is at the core of the ocean food chain. The plants are a source of food for other marine life, and happen to take up and bind carbon dioxide as well. They rely on the availability of nutrients to grow – most commonly nitrogen or iron. Fertilising the oceans with iron sulphate is believed to increase their growth and reproduction, which would in turn increase the amount of carbon dioxide they take up, reducing the effect of carbon emissions. Some scientists also believe that the increased marine plant life may increase the number of fish in the sea, in turn improving our food supply.

❷ Microalgae bloom
The rich iron supply creates vast blooms of tiny marine plants, which take up CO_2 as they grow.

❸ Carbon locked away
As the plants die, some fall to the ocean floor, taking locked-up carbon dioxide with them which becomes buried as sedimentary rock.

Carbonate addition
Adding powdered limestone – an alkali – to Earth's oceans could counteract the acidifying effects of greenhouse gases. Alkaline oceans also absorb more CO_2 from the atmosphere, but changing seawater alkalinity might harm certain marine life.

carbon dioxide out of the atmosphere with any of them," explains Professor Ridgwell. "They lend themselves to gradual mitigation."

Growing vast new forests or fast-growing crops competes with existing land uses, explains Dr Tim Lenton from Exeter University. The idea is to repeatedly harvest fast-growing crops like eucalyptus, which capture the carbon dioxide they use to grow. Crops growing on the best soils take up the most carbon, but you want to use those soils to grow food. "The plausibility problem is that you're in potential competition with other land uses in a world where dietary demands are rocketing."

Reflecting sunlight back into space with aerosols is the fastest geoengineering method. It mimics the rapid cooling effect of a large volcanic eruption. "Once you start blocking out some sunlight, temperatures drop quite quickly," explains Andy Parker. For example, in the two years following the eruption of Mount Pinatubo in the Philippines in 1991, global temperatures cooled by about 0.5 degrees Celsius (0.9 degrees Fahrenheit) on average.

So realistically how fast could we cool the planet? Dr Hunt concludes: "Let's suppose the Greenland ice sheet completely melts and we get a one-metre [3.2-foot] sea-level rise. It could be done in five years – if we've got time to think about it, 20-30 years from now." ⚙

Can we stop a hurricane?

Hurricane Katrina in 2005 was arguably the worst natural disaster in American history, and many scientists believe hurricanes will only worsen with climate change.

So there's no shortage of ideas for stopping these devastating storms. In 2009, Bill Gates backed a proposal to halt hurricanes by towing tub-like barges into their path. These would cool the warm ocean waters fuelling the storm.

Most plans underestimate a hurricane's power though; according to the NOAA Hurricane Research Division, one storm can release the energy of 10,000 nuclear bombs. For example, to fight a hurricane with water-absorbent powder you'd need hundreds of planes to make sorties every one and a half hours.

Some therefore argue that it's cheaper and more practical to adapt to hurricanes by, for instance, building stronger houses.

The risks of geoengineering

Geoengineering is controversial because it involves large-scale changes to Earth's climate. Critics discuss possible negative side effects, like that ocean fertilisation might cause toxic algal blooms, or that geoengineering gives industry and government excuses not to cut carbon emissions.

Geoengineering also raises issues of ethics. Cooling the climate with sulphate aerosols "is potentially cheap enough for single countries to do", says Professor Andy Ridgwell, Bristol University, but could impact other countries' climates as well.

Others fear 'rogue' geoengineers. For example, an American businessman dumped 100 tons of iron sulphate into the Pacific in July 2012 in an unauthorised ocean fertilisation scheme.

© Weather Modification, Inc/Christopher Grilliot/Bruce Boe; SPL; Peters & Zabransky; NASA

Wind tunnels

Allowing engineers to test aircraft designs in the lab, wind tunnels are invaluable to scientific research

A wind tunnel simulates in a laboratory the flow of air around, for example, an aeroplane or a building. This allows designers to work out the impact this airflow will have on the finished product and make cars and planes more aerodynamic and structures more wind resistant.

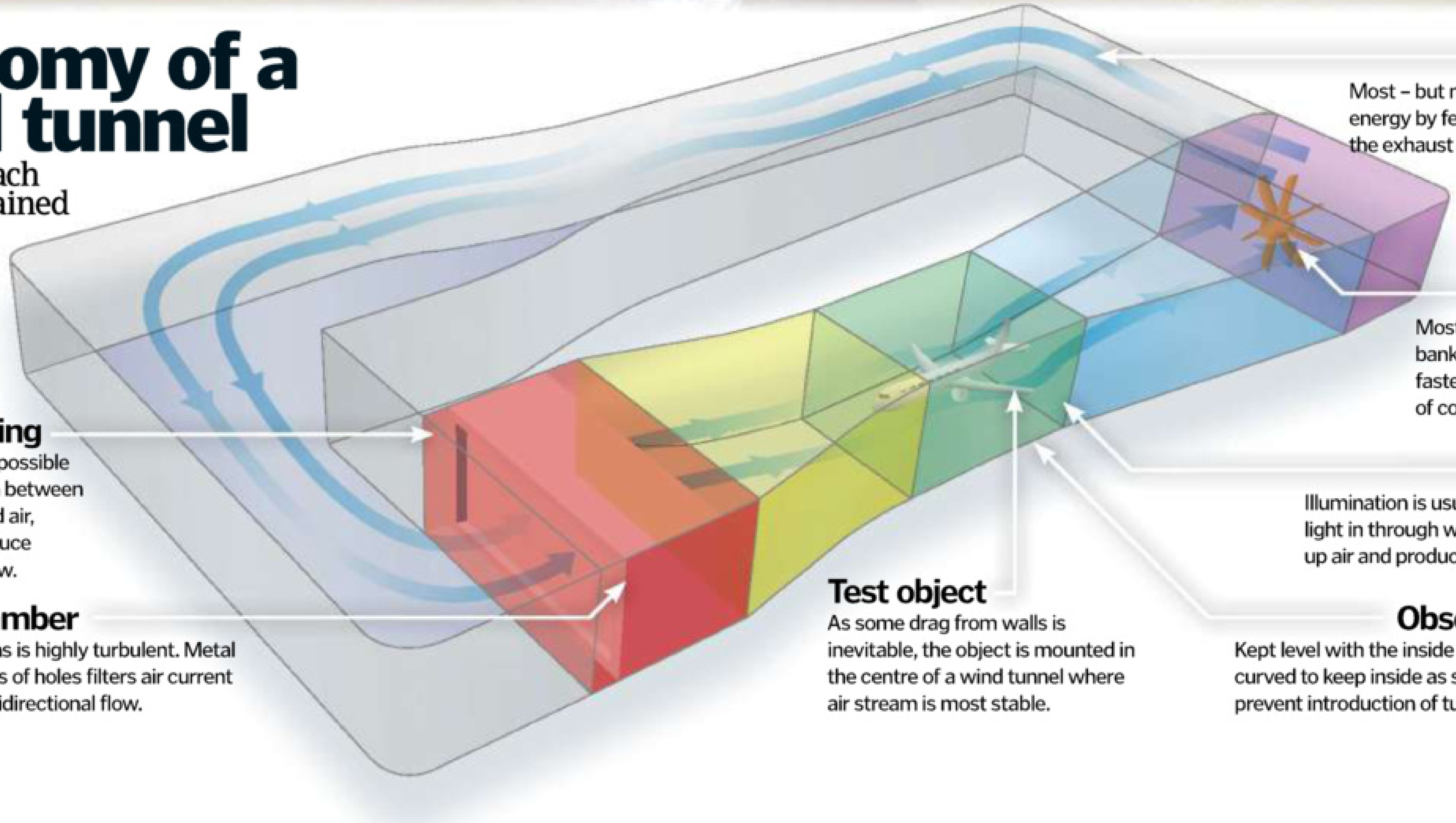
Wind tunnels are large circular tubes through which air is blown in one direction by giant fans: the test object – usually a scale model of the actual design – is mounted in the centre. In the case of an aircraft or a plane, in reality the object will be moving while the air stays still, but this doesn't matter as long as the relative velocity between the air and the object is the same. An enclosed cylinder is needed to allow for uniform airflow in one direction (known as laminar flow), simulating the airflow past a plane moving in a straight line or the wind hitting a skyscraper. ✽

Testing in the supersonic wind tunnel at NASA's Lewis Flight Propulsion Laboratory

Both photographs © NASA

Anatomy of a wind tunnel

The role of each section explained



Closed loop
Most – but not all – wind tunnels save energy by feeding the moving air from the exhaust back to the input.

Fans
Most wind tunnels use fans or banks of fans, although the very fastest use explosive expansion of compressed air.

Lighting
Illumination is usually provided by shining light in through windows – lighting would heat up air and produce turbulence.

Observation windows
Kept level with the inside of wind tunnel and usually curved to keep inside as smooth as possible and prevent introduction of turbulence.

Test object
As some drag from walls is inevitable, the object is mounted in the centre of a wind tunnel where air stream is most stable.

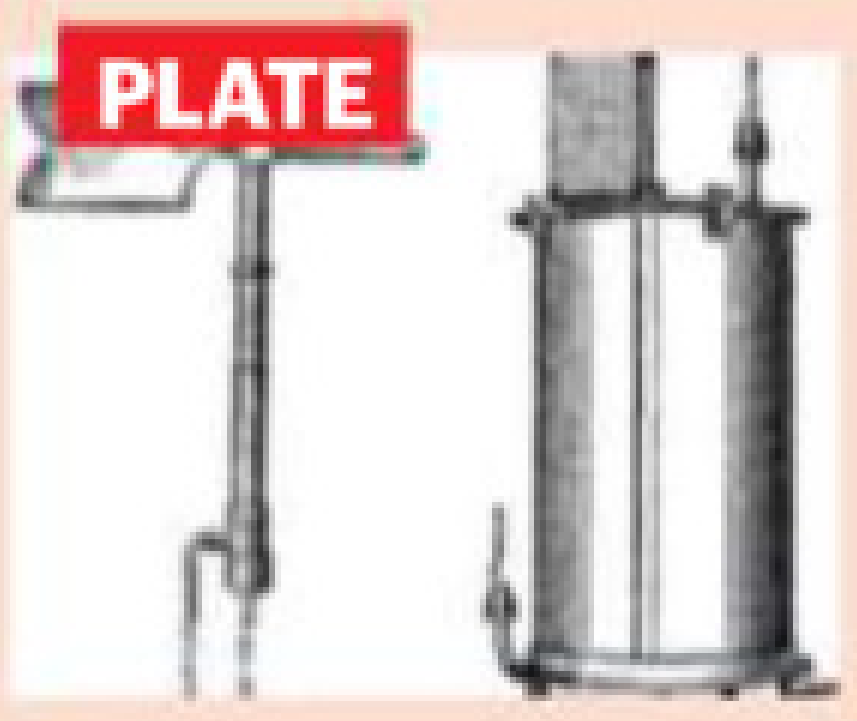
Internal casing
Kept as smooth as possible to minimise friction between the wind tunnel and air, which would introduce turbulence to airflow.

Settling chamber
Air produced by fans is highly turbulent. Metal grating with a series of holes filters air current to create stable, unidirectional flow.

HEAD2HEAD
TYPES OF ANEMOMETER

1. Mechanical

Facts: These mechanically based anemometers are not the most precise and accurate way of measuring wind speeds, but they are the most commonly used due to their simplicity and ease of use.



2. Pressure

Facts: The earliest kinds of anemometers, they work by measuring the pressure wind can place on a set area, which in turn depresses a spring. However, they only work for high strength winds.

3. Sonic

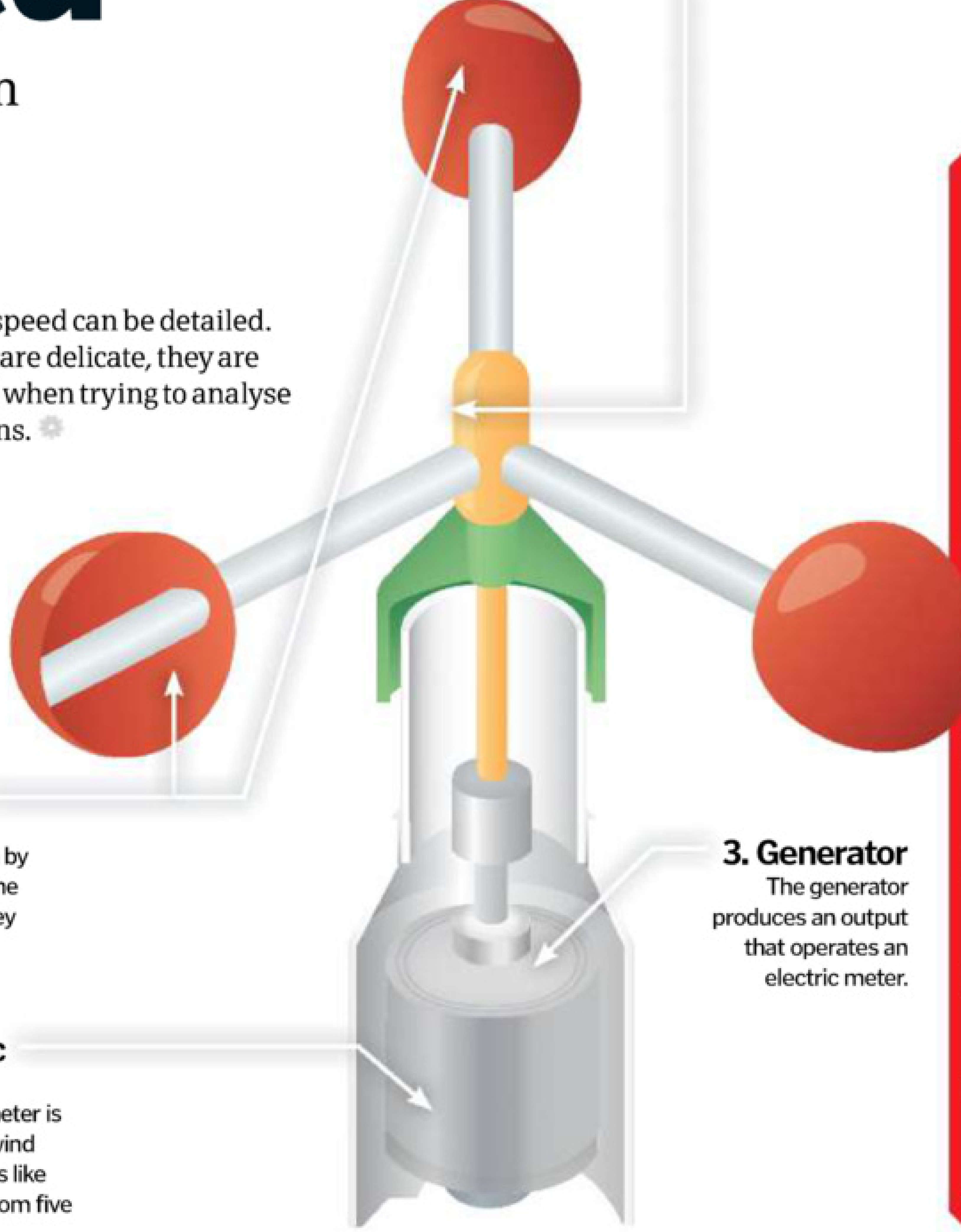
Facts: Ultrasound anemometers work through transmitting sonic pulses between two receivers. The delay in receiving these pulses can be analysed in order to gauge wind resistance, therefore speed.

Measuring wind speed

Anemometers can often be spotted in weather stations, but how do they actually give information to meteorologists about wind speed?

There are several types of anemometer employed to gauge wind speed, but the one we would most probably recognise is the cup anemometer. These have three cups spaced equal distances apart on arms horizontal to a central shaft. The cups catch the air as it drives past them, causing the shaft to spin. By counting the number of turns occurring in a second, you can then calculate the average wind speed. Some cup anemometers also have tiny electricity generators built into them that calculate wind speed by analysing how much energy the spinning anemometer is creating instead of counting the spins.

There are also many other types of anemometers, which work using lasers, ultrasound measurements, pressure sensors or temperature sensors. Hot-wire anemometers, for example, work through the heating of a fine wire to a set level above ambient atmosphere temperature, and then by the precise recording of the speed of cooling caused by wind passing the wire, wind speed can be detailed. Although these are delicate, they are extremely good when trying to analyse wind fluctuations.



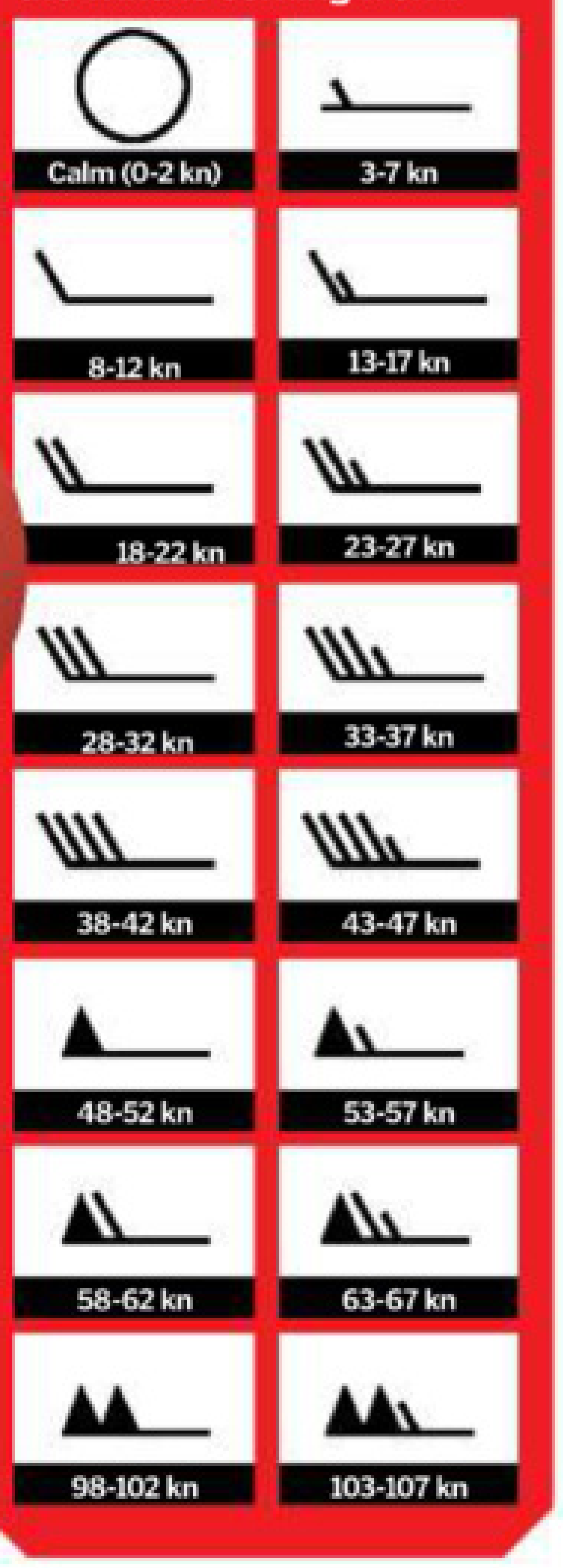
2. Spindle
As the spindle turns it drives a small electric generator located beneath it.

1. Revolving cups
The cups are driven by the wind and turn the spindle to which they are attached.

3. Generator
The generator produces an output that operates an electric meter.

4. Electric meter
The electric meter is calibrated in wind speed. Devices like these range from five to 100 knots.

Wind speed is measured in knots and wind barbs show the direction and speed of winds on weather maps. They point in the direction the wind is coming from.



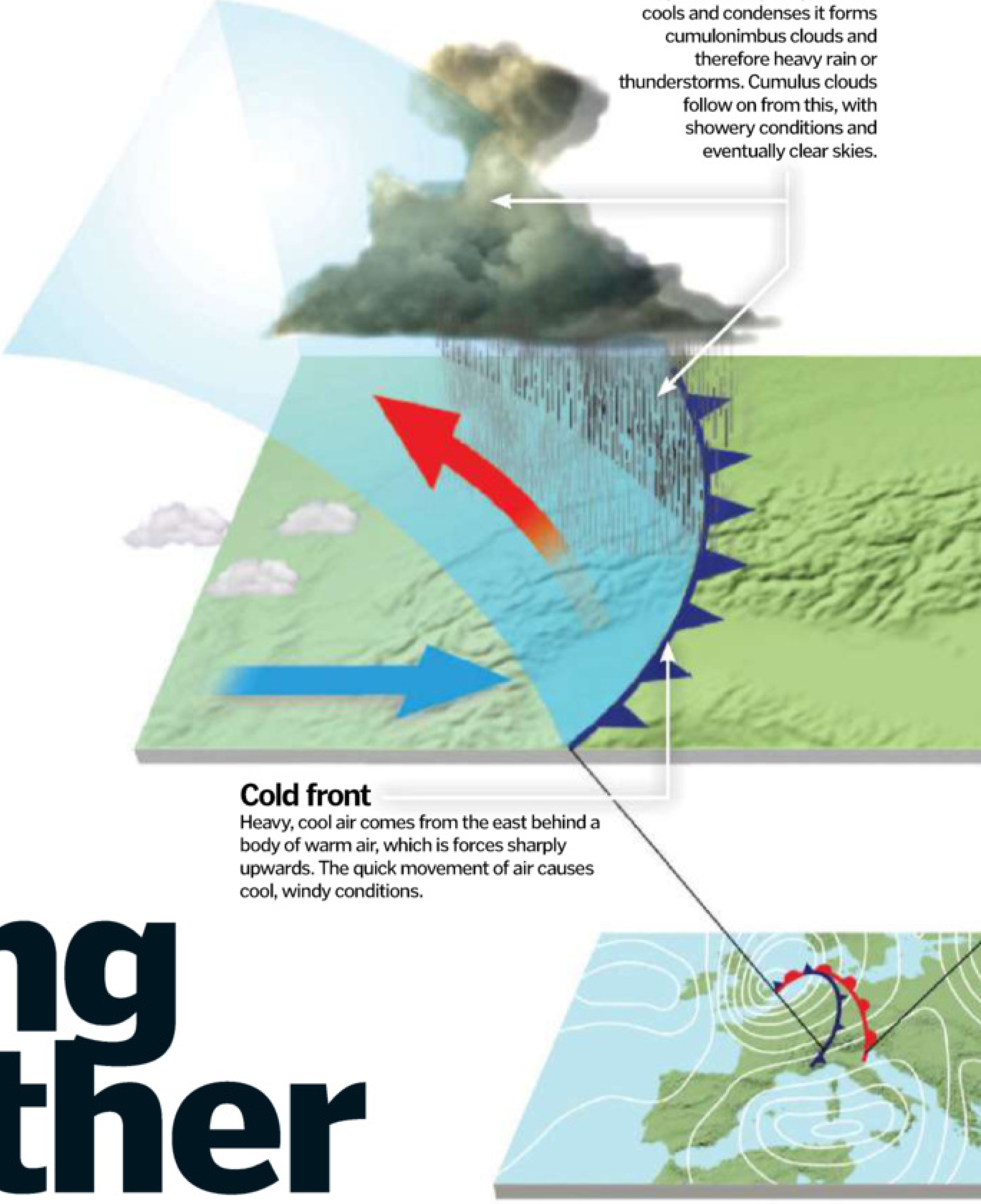
Sunblock

How does sunblock protect your skin?

The largest organ of the body, your skin is an amazingly durable and sophisticated substance, and yet it remains vulnerable to the Sun's ultraviolet rays. Apart from covering up with clothing, the next best way to protect this precious layer is to wear sunscreen. The Sun undoubtedly has its benefits: for example, exposing skin to sunlight enables the body to produce vitamin D, which is essential to healthy bones. However, you still need protection, not only from the UVB rays that cause sunburn, but also from the UVA rays that penetrate into the skin and damage cells, causing ageing and leading to a higher risk of skin cancer.

Sunscreens can work in two ways and contain either organic chemical compounds, physical ingredients, or a combination of the two. While chemical sunscreens absorb the UV light that tries to pass through them, physical sunscreens act like a natural mirror that reflects the rays away from the skin, making it safer for you to enjoy the sunshine, just don't forget to reapply!

Looks like high pressure has moved in...



Cold front conditions

As the warm air is forced upwards so quickly, when it cools and condenses it forms cumulonimbus clouds and therefore heavy rain or thunderstorms. Cumulus clouds follow on from this, with showery conditions and eventually clear skies.

Cold front

Heavy, cool air comes from the east behind a body of warm air, which is forces sharply upwards. The quick movement of air causes cool, windy conditions.

Predicting the weather

To take an umbrella or not? How we get those all-important forecasts…

The simple fact of the matter is that weather is unpredictable. So how is it that we can gather information and make predictions about what conditions on Earth will be like?

Most weather phenomena occur as a result of the movement of warm and cold air masses. The border between these bodies of air are known as 'fronts', and it's here that the most exciting weather, including precipitation and wind, occurs.

As a body of air passes across different types of terrain – such as over the oceans, low-lying areas or even mountainous regions – air temperature and moisture levels can change dramatically. When two air masses at different temperatures meet, the less dense, warmer of the two masses rises up and over the colder. Rising warm air creates an area of low pressure (a depression), which is associated with unsettled conditions like wind and rain.

We know how a frontal weather system will behave and which conditions it will produce down on the ground. The man who first brought the idea of frontal weather systems to the fore in the early 20th Century was a Norwegian meteorologist called Vilhelm Bjerknes. Through his constant observation of the weather conditions at frontal boundaries, he discovered that numerical calculations could be used to predict the weather. This model of weather prediction is still used today.

Since the introduction of frontal system weather forecasting, the technology to crunch the numbers involved has advanced immeasurably, enabling far more detailed analysis and prediction. In order to forecast the weather with the greatest accuracy, meteorologists require vast quantities of weather data – including temperature, precipitation, cloud coverage, wind speed and wind direction – collected from weather stations located all over the world. Readings are taken constantly and fed via computer to a central location.

Technology is essential to both gathering and processing the statistical data about the conditions down on Earth and in the upper atmosphere. The massive computational power inside a supercomputer, for example, is capable of predicting the path and actions of hurricanes and issuing life-saving warnings. After taking the information collected by various monitors and sensors, a supercomputer can complete billions of calculations per second to produce imagery that can reveal how the hurricane is expected to develop.

HEAD2HEAD

FREAKY WEATHER

1. Moonbows

These are rainbows caused by moonlight. They often appear white to the naked eye, and appear best with a full moon.

2. Sundogs

A phenomenon whereby there appears to be more than one sun in the sky. Sundogs are faint rings of light created when horizontal ice crystals in the atmosphere align to refract light.

3. Raining animals

It has been known to 'rain' frogs and fish. It is thought that the animals are picked up during tornadoes over water.

DID YOU KNOW? *The MET office has more than 200 automatic weather stations in the UK; they are usually 40km (25m) apart*

Warm and cold fronts

What do these terms mean and how do they affect us?

In practice

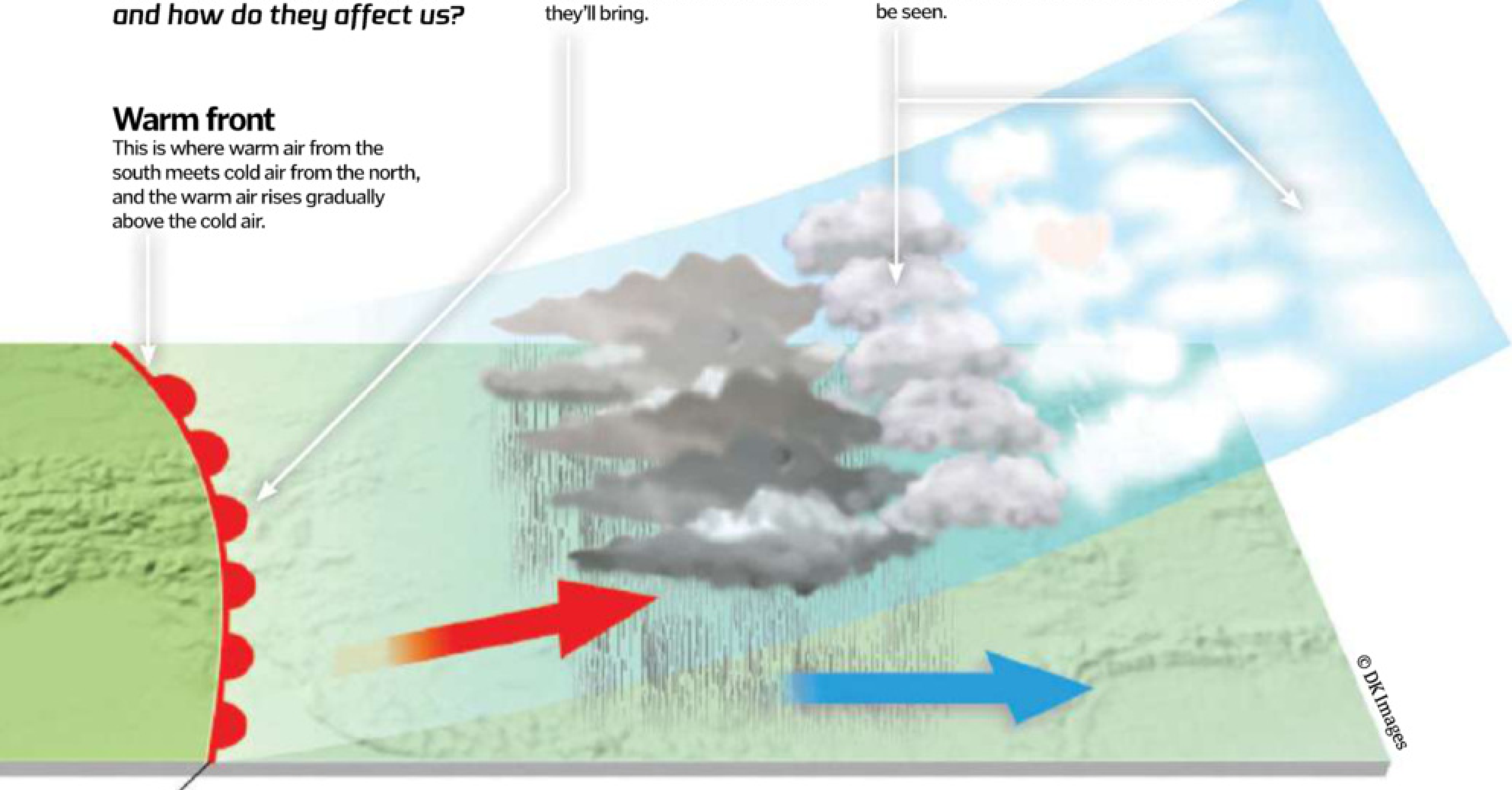
The red curves of a warm front and blue triangles of a cold front are shown on a map to show where the fronts are, where they're heading and the weather they'll bring.

Warm front conditions

As the warm air slowly rises, it cools and condenses and clouds are formed. These are nimbostratus, causing steady rainfall, then altostratus accompanied by drizzle, and finally cirrus, when clearer skies can be seen.

Warm front

This is where warm air from the south meets cold air from the north, and the warm air rises gradually above the cold air.



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WEATHER FORECAST MAP

Learn what these weather-related signs and symbols mean

High pressure

Weather here will be clear and dry, due to the high pressure. If this high pressure occurs in summer weather will be warm, whereas in winter it will be cold and crisp.

Wind

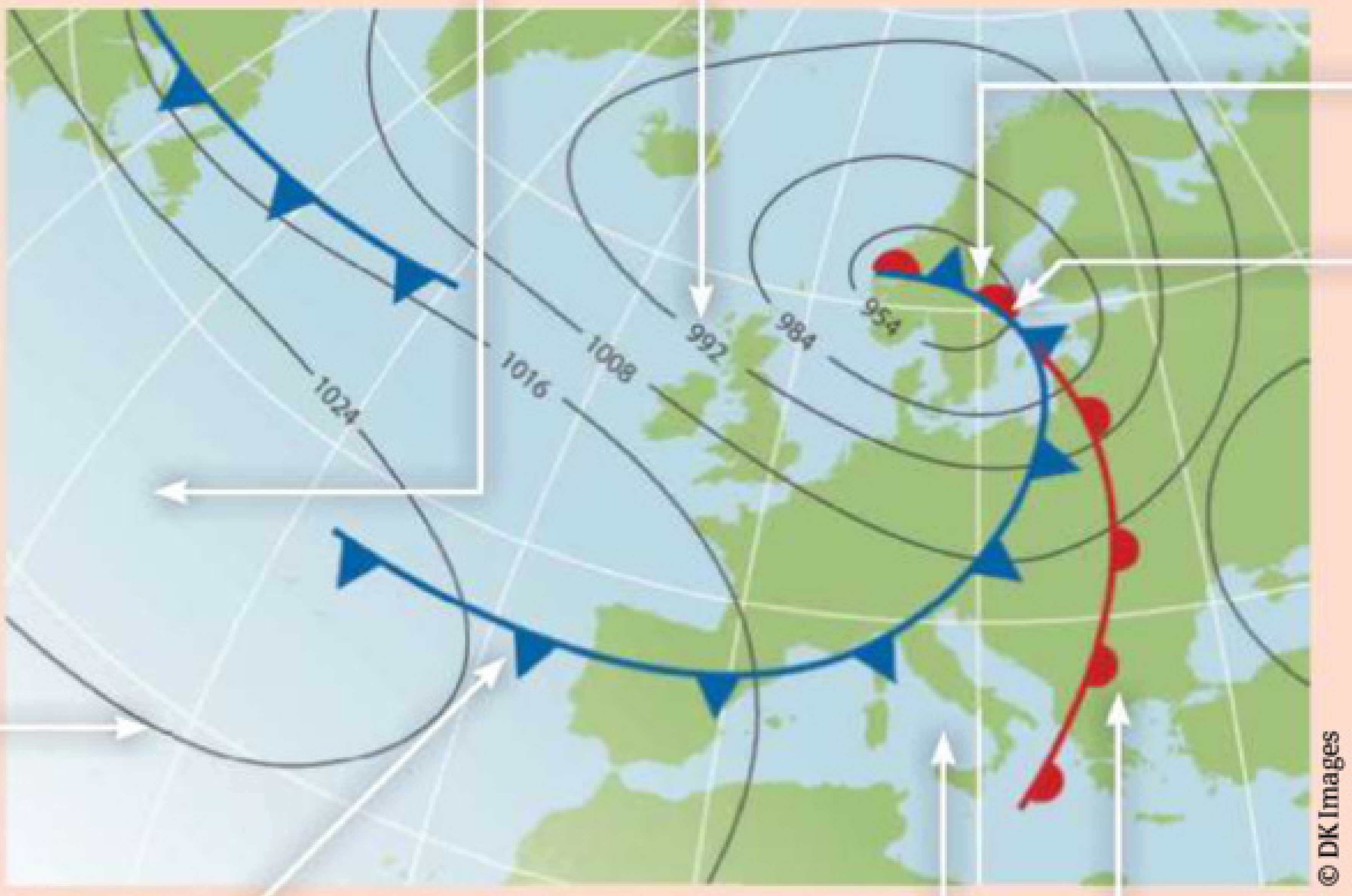
The conditions at this point will be windy. This is indicated by the position of the isobars; the closer together they are the windier the conditions.

Low pressure

At the centre of these circular patterns of isobars is where systems of high or low pressure lie. Where there is low pressure conditions will be rainy and windy.

Isobars

These indicate atmospheric pressure. Areas of equal atmospheric pressure are joined together with the lines shown and the numbers indicate pressure measured in millibars. Lower numbers indicate low pressure, while higher numbers indicate high pressure.



© DK Images

Occluded front

This is where one front 'catches up' with another. In this example, the cold has caught up with the warm. Occluded fronts cause the weather to change quite quickly and, in this case, become similar to that of a cold front.

Cold front

As with any cold front, the weather here will be expected to be cool with heavy rainfall and possibly even thunderstorms. This will be followed by showers.

In between

After the passing of the warm front and before the arrival of the cold front conditions should be clear and dry, but normally only for a short period.

Warm front

The warm front will cause steady rainfall, followed by drizzle, accompanied by cloudy skies. These are typical conditions caused by any warm front.

Stormy weather

Hail

The tops of storm clouds are full of tiny ice crystals that grow heavier until they fall through the cloud. The biggest hail stone on record was 17.8cm (7in).

Lightning

A flash of lightning is a giant spark caused when the molecules in a thunder cloud collide and build up static electricity. The flash occurs when a spark jumps through a cloud, or from the cloud to the ground, or from one cloud to another.

Thunder

This is the noise produced by lightning. An increase in pressure and temperature cause the air nearby to rapidly expand, which produces the characteristic sound of a sonic boom.

Storm cloud

Your typical run-of-the-mill cloud can be hundreds of metres high. A storm cloud, however, can reach heights of over ten kilometres (that's six miles).

How many...?

16 million thunderstorms occur each year globally.

Michael Fish

On the Met Office, predicting the weather and *that* 1987 forecast

As the jokes go, whenever rain is forecast, there will be sunshine and whenever sun is forecast, it will rain. But there is no instance more memorable than when Michael Fish MBE assured the nation that the Great Storm wasn't coming. On 15 October 1987, Fish denied plausibility of a report of an incoming storm. Then the storm hit.

We spoke to Fish about his love of the weather and his aspirations to experience being at the centre of a hurricane.

You started your education at Eastbourne College. What did you do there that led you towards meteorology?

Lots of people ask me that and I'm never really sure about the answer, but I think it was triggered by the horrendous floods of 1953. Along the east coast and in Holland nearly 2,000 people drowned. Although I have a feeling I would have developed an interest anyway, that was such a major weather event that I think it was *the* trigger.

How did you get in to the Met Office?

I was determined to join the Met Office so I went on to get the right qualifications. I studied and passed Maths, Physics and Chemistry at A-level then went straight into the Met Office within a few weeks of leaving school. And in those days it was quite easy to step into the career you wanted. I know these days, of course, I would imagine it's much more difficult as the Met Office is hardly recruiting these days.

I just had an interest in that sort of thing; you have interests, and my interest was weather. I wanted to be a weather forecaster. There was nothing about radio or television that attracted me, so the goal was purely to be a weather forecaster or possibly even doing some research into atmospheric sciences.

What technology or science did you use to predict the weather?

Well, when I first joined the Met Office there was no such thing as technology really. Your tools were a pencil and rubber. In the early Sixties the Met Office got its first computer and produced its first numerical forecast. We also got the first weather satellites, which was a giant leap forward. But even so, the basic forecast was done by human beings with a pencil and rubber. It wasn't possible to do forecasts for more than a day or two ahead due to the lack of facilities and computing power. And now, with the world's biggest computer, it's possible to forecast for ten or fifteen days with no problem whatsoever. It is predicted that they'll be able to produce really accurate forecasts that pinpoint things to a few hundred metres and look weeks and maybe months ahead. No human being could ever do that.

Do you think it will make individuals like yourself irrelevant?

There will always be a human to interpret the information. Unless you can teach the computer to speak, then I suppose you won't need a weatherman on the radio. But no, a human being has to keep an eye on the input and output because computers don't think for themselves. It can blindly take in duff information and calculate the mathematics completely wrong. Otherwise you can leave the computer to do the job better than you could.

Naturally I have to ask about the Great Storm of 1987, could you take me through your day?

I can't really remember most of it. I wasn't even on duty. Bill Giles was the forecaster on duty the afternoon and evening before, and he gave a very low-key forecast about it being breezy up the channel. The previous day I had said, "Batten down the hatches, there is some extremely stormy weather on the way."

As far back as the previous Sunday, the computer had predicted that there would be horrendous gales at the end of the week. But as it got nearer and nearer to the event, the computer slowly changed the track of this particular deep area of low-pressure. So where on the Sunday it had forecast the storm to hit south-east of England – which is where it did hit – by the Friday morning, when I was on duty, it said it was going to cross northern France and we were only going to experience strong winds. Hence why Bill Giles said it was going to be breezy up the channel.

But, of course, Sod's Law decreed and at the very last moment it changed course and caused the devastation we saw. It's unfortunate that the computer didn't get all the information it would usually get to do its sums.

The Great Storm aside, what would you say was your most life-altering experience of extreme weather?

I think it was during my first month at the Met Office, when I was working at Gatwick Airport. London had its last great smog and all flights to Heathrow were diverted to Gatwick. There was absolute chaos because the planes couldn't be parked anywhere. Shortly after that, at the end of 1962 to the beginning of 1963, we got the most severe winter that the country's seen for over 100 years. Everything in the house froze up, I froze up and all the rest of it. It was quite a dramatic welcome to the Met Office, with some of the most severe weather for hundreds of years being forecast.

If there was one extreme weather event you would like to experience in your life, what would it be and why?

I want to experience a hurricane. I want to go on one of the American Weather Bureau flights that run into the centre of a hurricane in order to take measurements of the wind, the pressures and so on. Or if that was not possible, I would get myself in a safe place and experience a hurricane on the ground. I've done storm chasing on a couple of occasions, so I have seen and experienced tornadoes, but I've never seen or experienced a hurricane. Or a typhoon. I'll go to Japan as well as America.

In the future, do you think we'll experience another Ice Age or feel the effects of global warming?

We're certainly not going to have another Ice Age for the very reason that global warming is having an effect. I give lectures on global warming which I title 'The Ultimate Weapon of Mass Destruction' because there is no doubt that millions of people have already died as a result of global warming.

Billions of dollars of damage has been done – not least to the British Isles early this year – and it's only going to get worse. It will be more severe everywhere. There are going to be more hurricanes, more floods, more typhoons, more devastation. The average temperature of the world will continue to rise and it could get to quite dramatic levels by the end of the century if nothing is done about it. The problem is even if we do something about it now, it's probably too late.

Do you think there is anything we can do about global warming?

We can slow it, but we can't stop it. What we have done already is going to continue for the next hundred years or more. But we can slow global warming and hopefully make it more manageable. But it is going to have to be done quickly to make a difference.

Catch Fish on **www.netweather.tv** every Thursday giving a video forecast and lectures on the impact of global warming.

"The problem is even if we do something about it now, it's probably too late"

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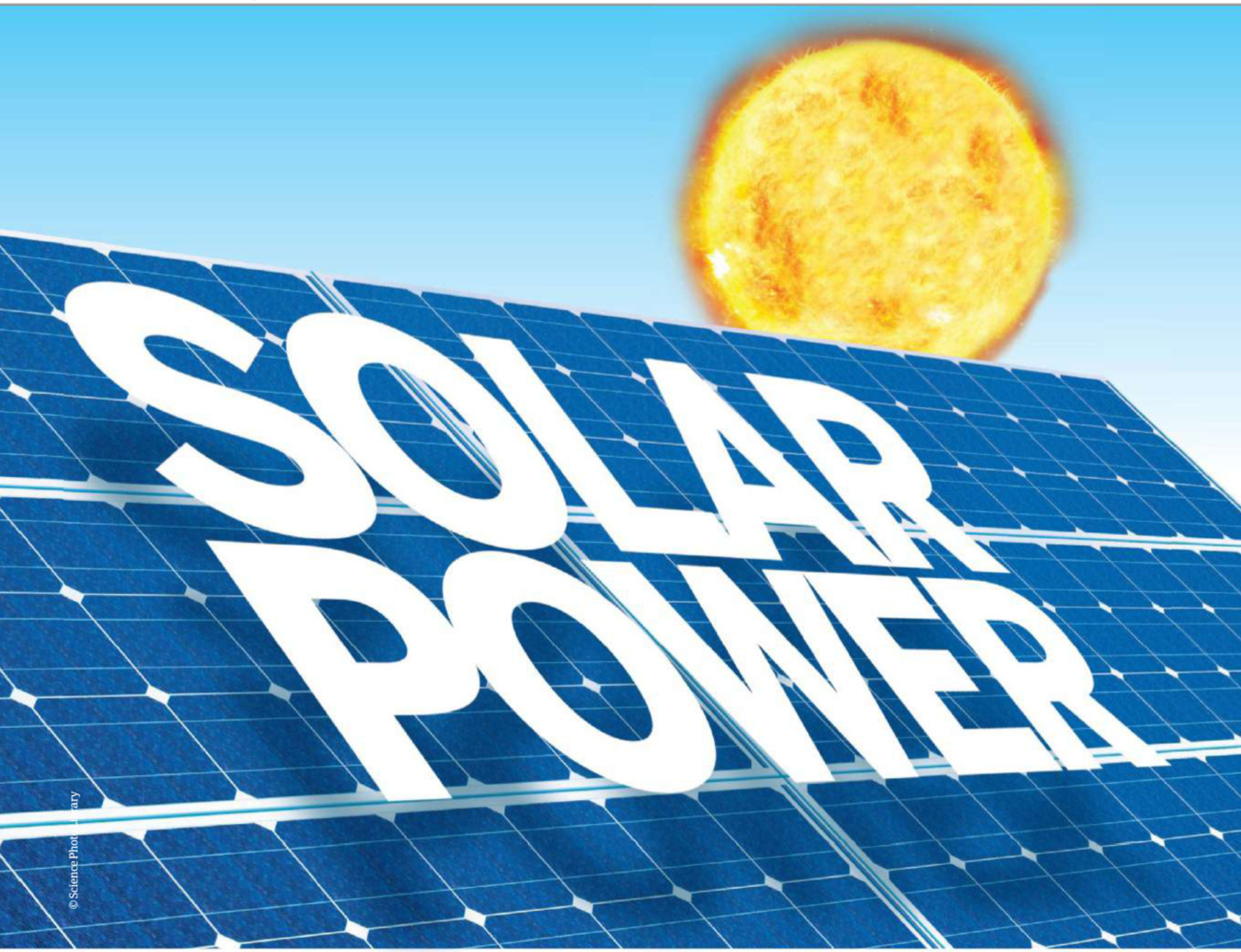


© Science Photo Library

Charge your gadgets, heat your home and even get paid for generating your own electricity

Renewable forms of power generation are essential. As the fossil fuels we currently rely on begin to run out, we need to find a replacement for the world's energy needs. The impact that burning oil and gas has on the environment must also be addressed if we are to stop and reverse the effects of global warming. One of the main forms of renewable energy that has now entered the mainstream is solar power.

Capturing even a fraction of the Sun's energy that hits the surface of the Earth could mean we are able to close our gas and coal-fired power stations. The Sun works by emitting solar radiation that is equivalent of 1,367 watts of power per square metre. This is known as the 'solar constant'.

The Sun is a massive fusion reactor, pumping out its energy (3.8 x 1026 joules per second) in all directions. On the Earth we only feel a fraction of this energy. The Sun actually delivers about 7,000 times more energy to the Earth's surface than we globally generate and use at the moment. The tricky part is capturing that incredible energy and using it efficiently.

Solar cells are properly known as photovoltaics, as the process of converting light (photo) into electricity (voltage) is achieved within the photovoltaic cell. When sunlight hits the cell, which is usually made out of silicon, it makes electrons come loose from the atoms they are attached to. This action produces electricity. The more sunlight that hits the cells the more electricity is produced, which you can then use to heat your water or charge your phone.

Across the world, every country is looking closely at how they can use more renewable energy sources. Not surprisingly, solar power is most popular in countries lucky enough to get sustained periods of sunshine. Spain and Portugal currently lead the way

5 TOP FACTS ALTERNATIVE POWERS

Wind

1 Wind is actually a form of solar energy caused by the Sun heating our atmosphere. Wind farms simply use the wind to drive a turbine that generates the electricity.

Nuclear

2 Nuclear reactors work by using fission, the splitting of atoms to produce energy. That energy is used to create steam that drives a turbine to produce electricity.

Tidal

3 Tidal turbines (like under water windmills), barrages or wave turbines all use the movement of the oceans or bodies of water to generate their electricity.

Geothermal

4 Water that's been turned into steam often escapes onto the surface of the Earth. Geothermal power stations capture that steam and use it to drive turbines.

Hydro

5 From water wheels to massive dams, harnessing the energy of falling water is the basis of hydropower, making it the most efficient renewable energy source available.

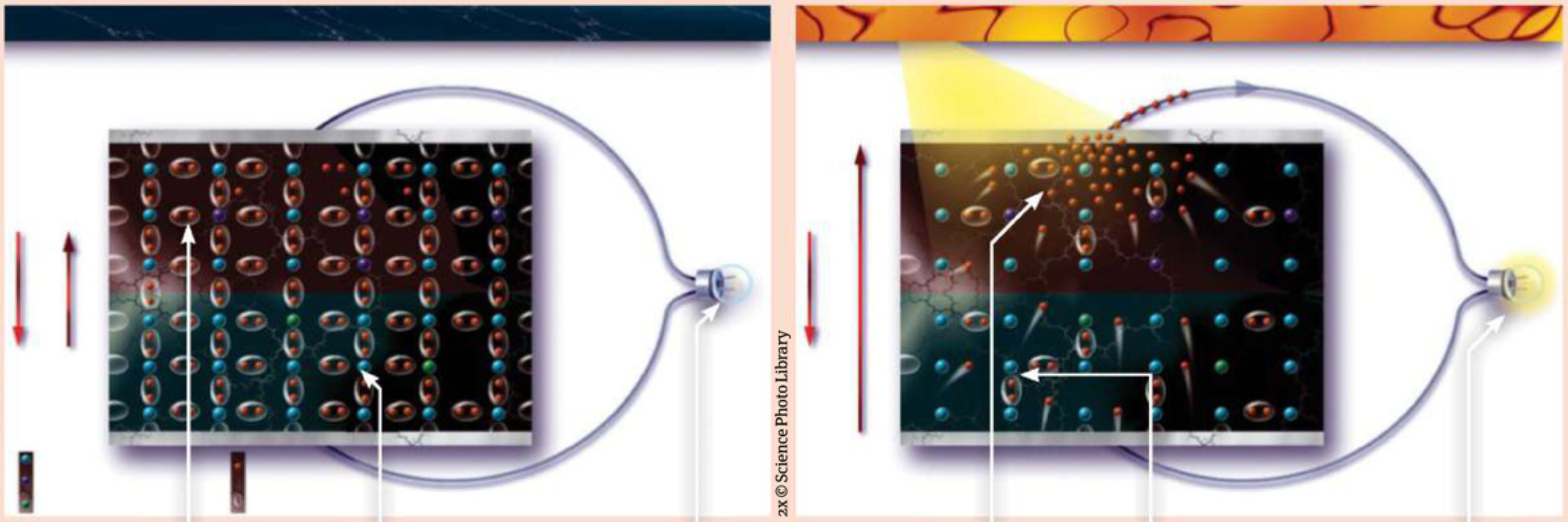
DID YOU KNOW? *Horace de Saussure built the first solar collector in 1776*

Photovoltaic cells in action

What goes on inside a solar cell on an atomic level?

If the sun isn't shining

If the sun is shining



2x © Science Photo Library

1. Atoms are not excited
No sunlight means the atoms remain at rest.

2. Sunshine will excite the electrons
Electrons will only break free when sunlight excites their parent atoms.

3. No electricity is produced
Without free-moving electrons electricity can't be generated.

1. Electrons set free
Sunlight agitates the atoms until their electrons are set free.

2. Some atoms will remain attached
Not all atoms are dislodged to create electricity.

3. A circuit is made and electricity is produced
The metal contacts make the circuit that illuminates the bulb.

This photovoltaic barrier was built in 2001 in Freising, Germany

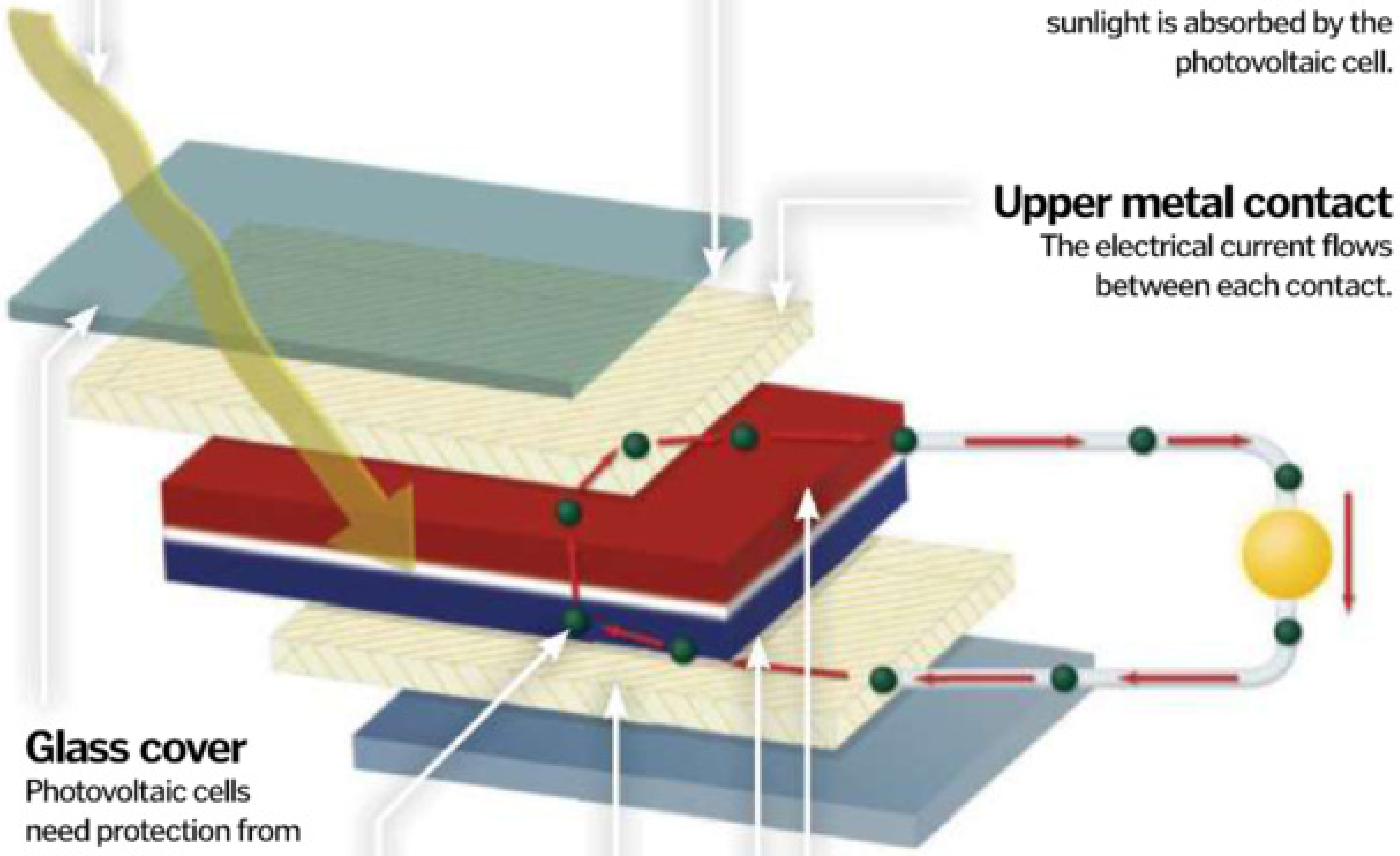
with ambitious plans to develop more of their energy generation via solar power, while America is planning to build the world's largest solar power station.

All this talk of solar energy and the fact that the Sun delivers much more energy than we need should be put into context – we don't yet have highly efficient solar cells to harness the free energy. If you compare the output of your gas boiler to that of the currently available solar cells, they're only around 18 per cent efficient.

However, this is still a massive leap forward from the 3-5 per cent efficiency that early solar panels could manage. The race is now on to develop more efficient photovoltaic cells to let us capture more of the Sun's precious energy. Current research is looking at organic photovoltaics, nanotechnology and even the ability to print solar cells onto just about any surface.

How solar cells work

A layer-by-layer breakdown of what's in a solar cell and how the different parts work



Sun light

Anti-reflection coating
The anti-reflection coating ensures sunlight is absorbed by the photovoltaic cell.

Upper metal contact
The electrical current flows between each contact.

Glass cover
Photovoltaic cells need protection from the weather.

Electron transfer
Sunlight frees electrons from their parent atoms and generates electricity.

Lower metal contact
Electrical current is captured between the upper and lower contacts.

N-type (negative) silicon
Impure silicon is used to create the negative part of the circuit.

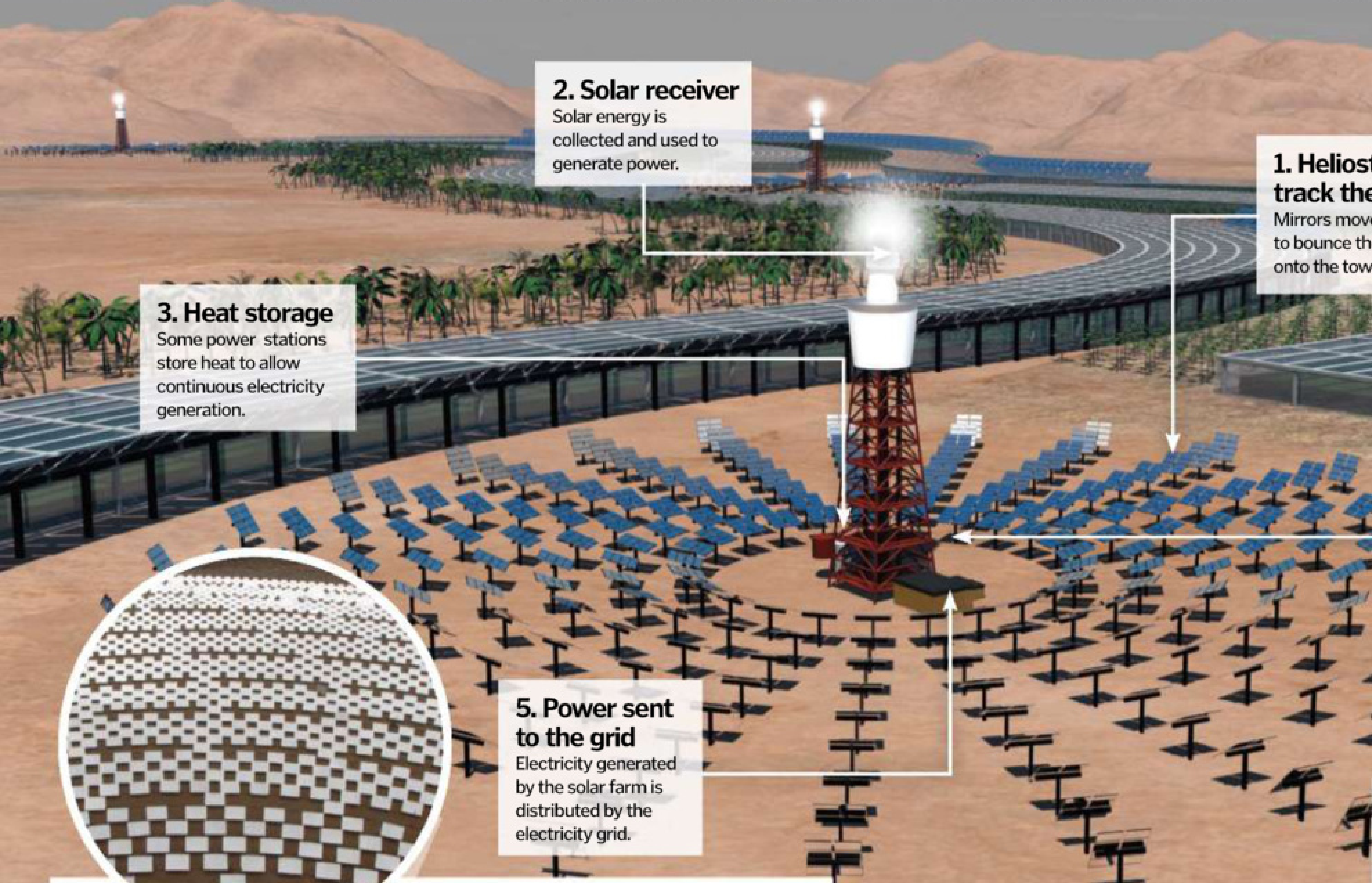
P-type (positive) silicon
Silicon with boron impurities creates the positive component of the circuit.

Solar power stations

Generating large amounts of power needs more than a few panels. Solar power stations generate electricity by creating steam that drives a turbine. The power to heat the water comes from the Sun.

Solar power stations use a series of computer-controlled mirrors called heliostats that track the movement of the Sun and reflect its energy onto a solar receiver on top of a tower at the centre of the station. The tower contains a boiler where the water is heated. Steam is then piped to steam turbines that generate the electricity fed into the grid for distribution.

Some more advanced solar power stations also divert some of the steam generated and store this for future use. This allows the power station to stay operational even at night, or when adverse weather conditions prevent the power station working at full capacity.



2. Solar receiver
Solar energy is collected and used to generate power.

1. Heliostats track the sun
Mirrors move with the sun to bounce the solar energy onto the tower.

3. Heat storage
Some power stations store heat to allow continuous electricity generation.

4. Steam turbine
Solar energy is used to create steam that drives traditional turbines.

5. Power sent to the grid
Electricity generated by the solar farm is distributed by the electricity grid.

© Matanya

© Science Photo Library

The mirrors track the movement of the sun

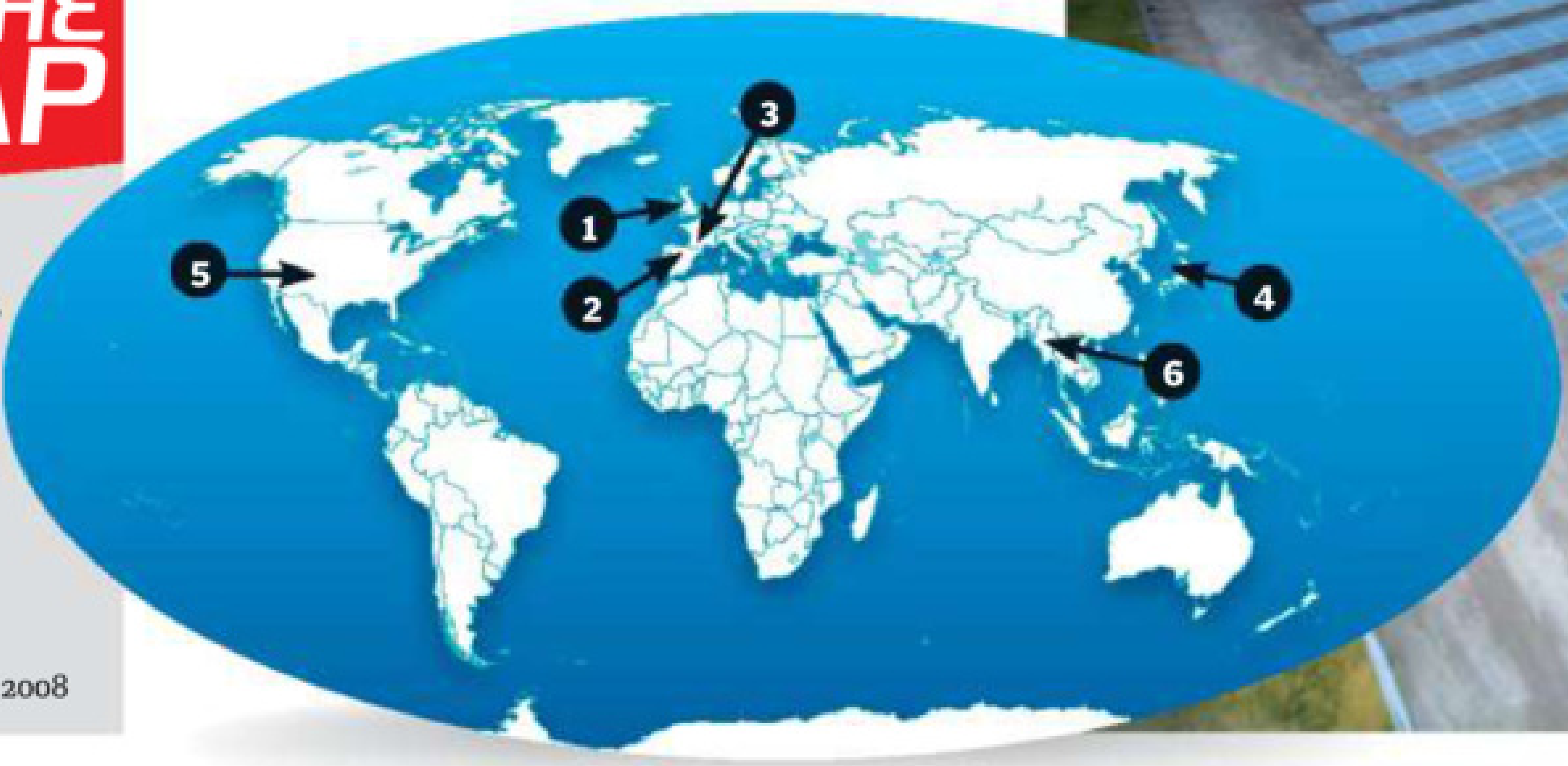
The PS10 plant in Spain has 624 heliostats

© Nosferatu.it

The panels come in all shapes, sizes and formations

© spg solar

ON THE MAP



Worldwide solar power generators

1 UK: 17 GWh
2 Spain: 2,562 GWh
3 Germany: 4,420 GWh
4 Japan: 2,251 GWh
5 USA: 1,572 GWh
6 China: 172 GWh

SOURCE: Gross Electrical Generation – Photovoltaics - 2008

HEAD 2 HEAD
SOLAR PANEL TECHNOLOGY

BIG

© NASA

1. International Space Station
The photovoltaic arrays connected to the American modules generate about 32kW over a surface area of 375m².

BIGGER

© solarcentury.co.uk

2. Howbery Business Park
As the UK's largest array of solar panels, the 3,000-panels generate up to 682 MWh and saves 350 tonnes of CO² each year.

BIGGEST

© courtesy of Enbridge Inc.

3. Sarnia Photovoltaic Power Plant
Covering a gigantic 966,000m², the 1.3 million solar modules can generate 80 megawatts of output to power 12,000 homes in Sarnia, Ontario, Canada.

DID YOU KNOW? *The Sun is 150 million km (93 million miles) away from the Earth. Sunlight takes eight minutes to reach us*

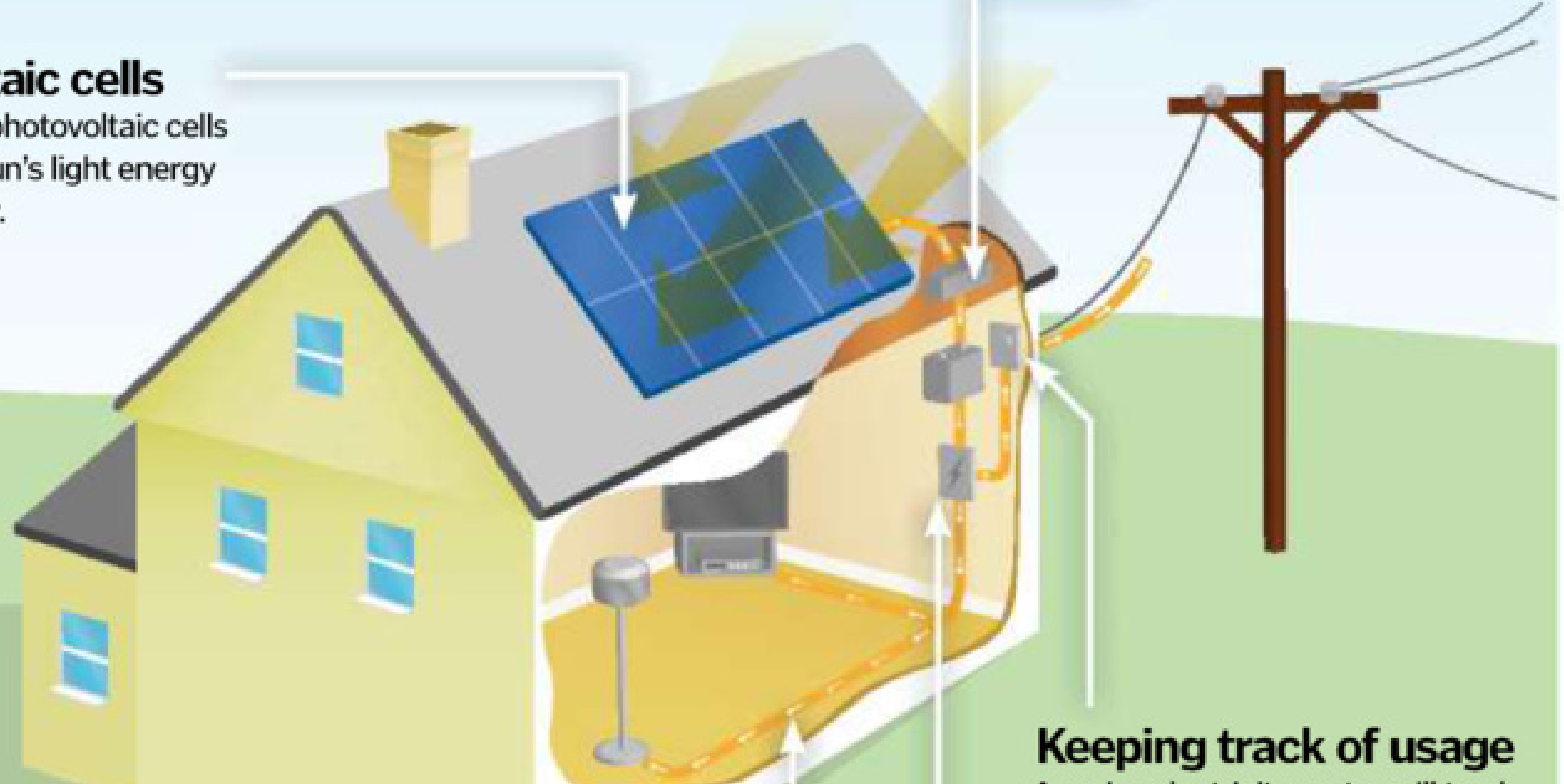
How to make and sell your own electricity

One of the great things about installing solar panels at home is that you can sell any surplus electricity you generate to your local electricity supplier. The feed-in tariff, or FIT, enables anyone to gain a minimum payment for the electricity they generate.

FIT works in two ways. Your local electricity company knows you generate your own power, so fixes the payments you make for the electricity you buy from them. The other part of FIT comes into play when your photovoltaic cells generate more power than you can use. Any extra you can sell to your electricity supplier at an agreed rate. In the United Kingdom this is currently 3p per kWh (kilowatt hour).

The practical upshot of FIT for anyone who installs solar panels and produces any excess is that they will receive a payment from their electricity company on an annual basis. The photovoltaic system that you install works with a meter that not only measures how much electricity you are using from the mains supply, but also what you are generating. This is how the electricity company can calculate your payments.

Creating your own solar power



Solar power converted to electricity
An inverter converts solar-generated power into AC electricity.

Photovoltaic cells
The installed photovoltaic cells convert the Sun's light energy into electricity.

Keeping track of usage
A mains electricity meter will track mains power and exported electricity.

Mains power is still available
When the Sun isn't shining mains power can still be used.

Main distribution box
Generated power is drawn just as if it were mains power.

Living off the grid

Life without the basic utilities might sound like a nightmare for some, but for an increasing number of people, living 'off the grid' has become a lifestyle choice. These people have not simply installed a solar panel or two, but chosen to remove themselves completely from the tether most us have to the grid and the other utility providers.

As you would expect, compromises have to be made. The amount of electricity you can generate will be dependent on the sunshine you receive, and of course there will be no long showers, nor running massive fridges when you're living off the grid.

The power that is generated is usually stored in batteries for later use, and to ensure some electricity is available when the Sun is absent. As photovoltaic cells can be attached to just about any structure or used free standing, they offer anyone who wants to live off the grid a readily available source of power.

© NASA

INTERVIEW

DuPont Senior Research Fellow Dr Bill Borland

How It Works: What is the state of the solar power industry today? Has its uptake in businesses and homes been increasing?

Bill Borland: The growth of solar power has been very impressive over the last few years, but it still represents less than one per cent of global electricity production. The adoption of solar power by homes and business is primarily driven by government subsidies. Being 'green' is an added attraction. Europe, particularly Germany, has had attractive subsidies in the form of feed-in tariffs that have promoted tremendous growth in homes and businesses. Growth in other nations, such as the USA, is emerging primarily from business rooftop installations.

HIW: Could you describe the process of making solar cells?

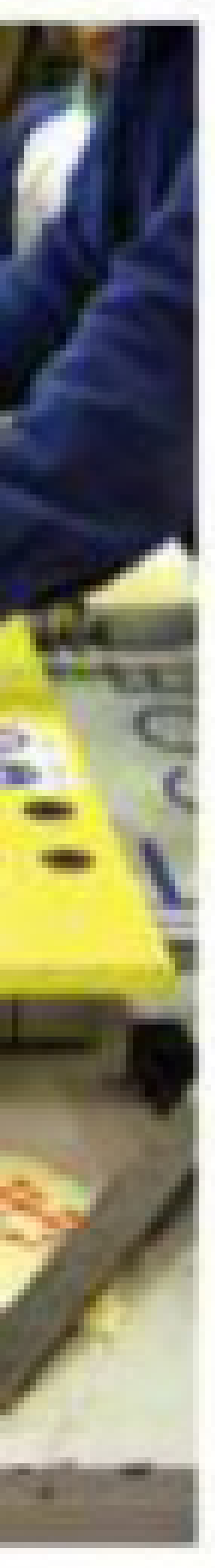
BB: The fabrication of a conventional crystalline silicon solar cell starts with texturing one side of a boron-doped silicon wafer that will become the front face. The wafer then undergoes a high-temperature phosphorus diffusion process to form the P/N junction. After removing phosphorus silicon glass, a by-product of the diffusion process, a silicon nitride anti-reflection coating is applied to the front face. This is followed by screen-printing silver paste on the front and aluminium and silver tabbing pastes on the back. The silver and aluminium pastes are rapidly co-fired to form the completed cell.

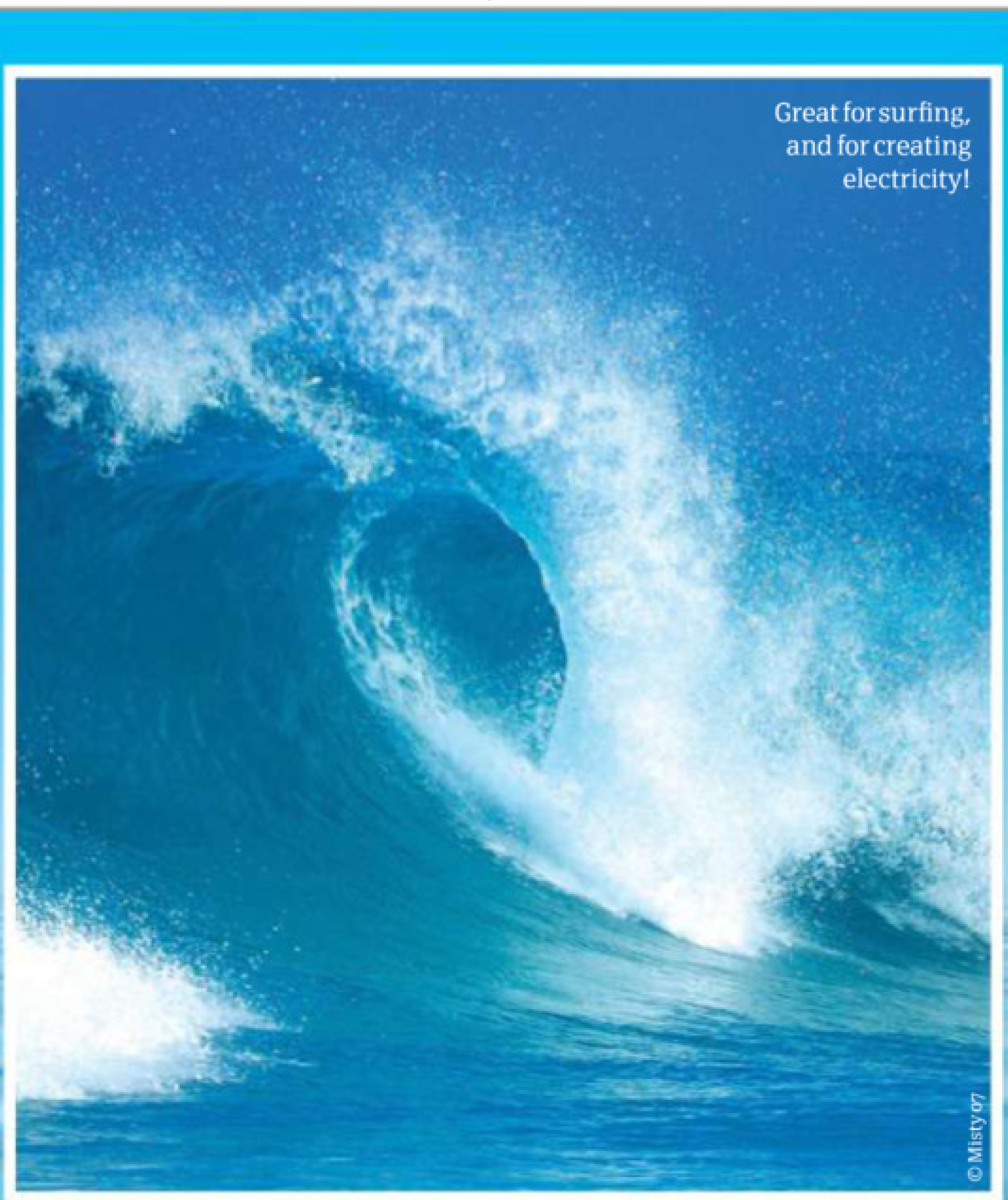
HIW: How do current solar cell technologies differ from those used in the past, specifically with regards to efficiency?

BB: Today's six-inch monocrystalline industrial solar cell comprises a textured and passivated front face, screen-printed silver contacts and a complete metal coverage at the back. The first cell in 1953 had an efficiency of 4.5 per cent. In 1960, with the introduction of the front finger grid, efficiency leapt to 14 per cent. Full metal coverage of the back in 1972 and texturing in 1974 raised the value to 17 per cent. In 1975 screen-printed contacts became common. Wafer sizes, however, were 2-3 inches. Since 1975, effort on increasing wafer sizes to six inches, Silicon Nitride passivation in 2002 and improved contacts have created today's 17.5-18 per cent efficient solar cell.

HIW: Are there any upcoming technologies that will improve the efficiency of solar cells?

BB: The drive-to-grid parity demands improved efficiencies without increasing cost. This means changes to the conventional solar cell. Technologies like selective emitters and rear surface passivation are expected to become mainstream and each can raise efficiency by up to one per cent. Technologies on the horizon include the use of N base cells instead of P base cells. N base cells are more tolerant to impurities, making them resistant to light-induced degradation of efficiency. Other developments include metal wrap through and all back contact cells, which could deliver efficiencies greater than 20 per cent.





Great for surfing, and for creating electricity!

© Misty 07

Power from the oceans

Ocean thermal energy is the latest in sustainable energy, here's how it works

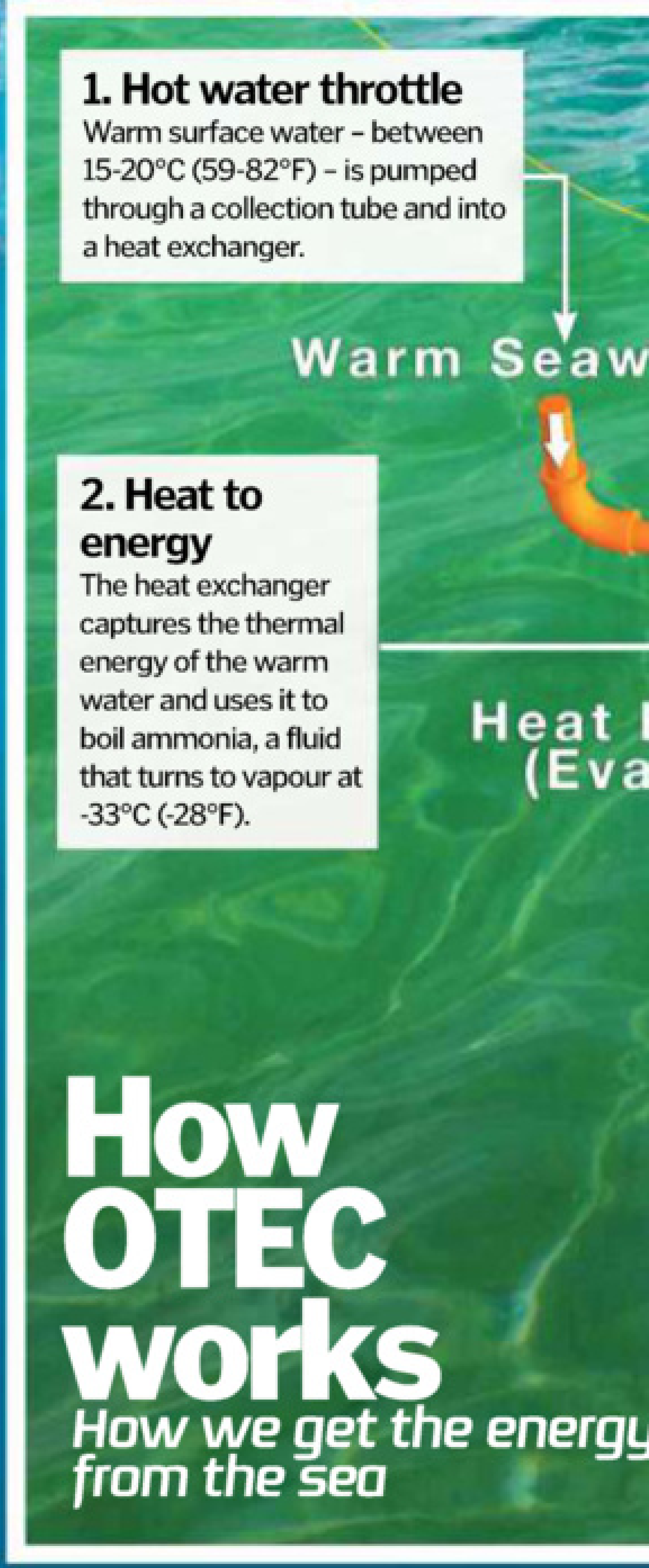
The world's oceans aren't separate bodies of water, but one vast sea connected by global currents. As warm tropical currents reach high latitudes, the cooling water sinks and turns southward. In certain tropical locations around the globe, the steamy surface currents and deep icy flows cross paths, creating tremendous temperature differentials between the shallows and 1,000 metres below.

Off the coast of Hawaii, where the temperature gap between shallow and deep waters is a constant 20°C (36°F), engineers are constructing the first large-scale 'energy island' that will convert the potential energy of the ocean into a clean, inexhaustible source of electricity.

The technology is called ocean thermal energy conversion (OTEC) and it's nothing short of revolutionary. The theory behind it sees warm surface water pumped through a heat exchanger, which pulls out the stored energy and uses it to boil an excitable fluid like ammonia. The forceful steam produced by the evaporating ammonia is funnelled into a generator, where it rotates a sequence of turbine blades, generating electricity.

But it doesn't stop there. A second heat exchanger pumps cold water from the depths to convert the ammonia vapour back to a fluid state, ready to be reused in the closed-cycle system. No fuel is burned and zero emissions are produced. The floating power plant can run 24 hours a day, 365 days a year exclusively on the heat differential of the ocean.

The pilot OTEC plant in Hawaii will generate a constant ten megawatts of electrical power, but commercial OTEC plants of the near future will easily reach the 100-megawatt mark, enough to power a small city.



1. Hot water throttle
Warm surface water – between 15-20°C (59-82°F) – is pumped through a collection tube and into a heat exchanger.

2. Heat to energy
The heat exchanger captures the thermal energy of the warm water and uses it to boil ammonia, a fluid that turns to vapour at -33°C (-28°F).

How OTEC works

How we get the energy from the sea

5 TOP FACTS OTEC

Seas of energy

1 The belt of tropical waters circling the planet stores 1,000 times more heat than the Earth's atmosphere, a great potential source of energy.

Sun sponge

2 An incredible 80 per cent of the solar energy that reaches the Earth's surface is then absorbed by the vast oceans that cover every corner of the globe.

Limitless potential

3 If we could capture even one-tenth of one per cent of the energy stored in ocean waters, it will equal the daily electricity consumption of the United States, times 20.

Squeaky clean

4 A conventional coal-fired power plant for a small city coughs up millions of tons of CO_2 per year. An OTEC plant powering the same city would produce zero.

New hope

5 Potential locations for OTEC sites include nations like Australia, but also third-world countries like Haiti, where clean OTEC power could revitalise economies.

DID YOU KNOW? *Every day, tropical waters absorb enough solar energy to equal heat generated by 250 billion barrels of oil*

Fringe benefits of using OTEC

During 35 years of OTEC research, engineers and scientists have discovered several other important, energy-saving uses for OTEC technology. The offices of the National Energy Laboratory of Hawaii Authority (NELHA), for example, are cooled year-round by deep seawater. Instead of refrigerating fresh water to circulate through its air conditioning system, NELHA pumps in 6°C (43°F) seawater, saving $4,000 a month on its electric bill. A luxury eco-resort in Bora Bora does the same thing.

Fresh, desalinated drinking water is another valuable byproduct of OTEC technology. Instead of using ammonia as a propellant, an 'open-cycle' OTEC system vaporises warm surface water in a near vacuum to power the turbines. By condensing the water vapour with a blast of deep-sea air, you're left with pure H_2O.

The electricity and fresh water created by the open-cycle OTEC process can also be used to produce pure hydrogen, the essential component of zero-emission hydrogen fuel cells. Using a device called an electrolyzer, it's possible to split fresh water into hydrogen and oxygen. The precious hydrogen could then be shipped to shore or around the world.

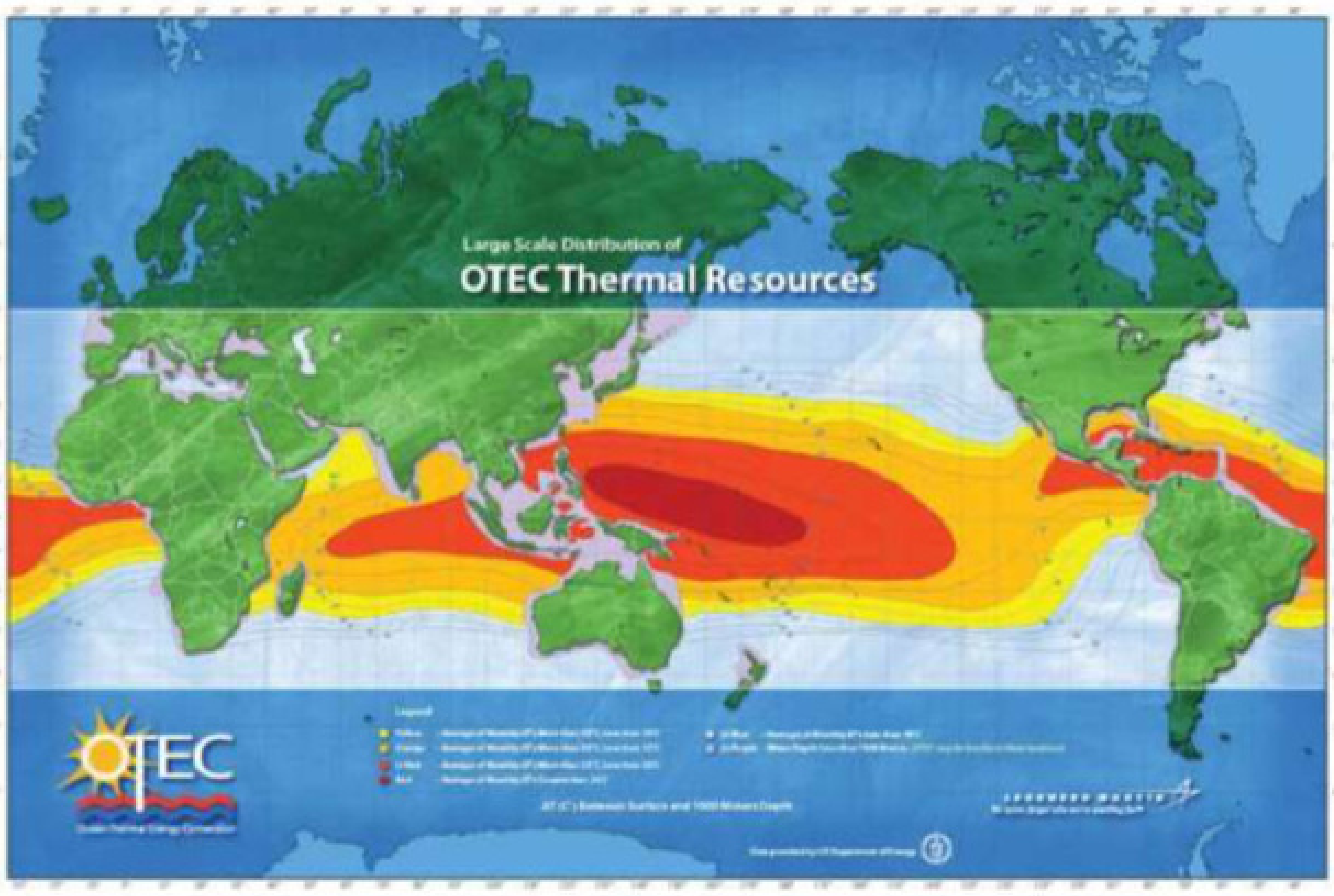
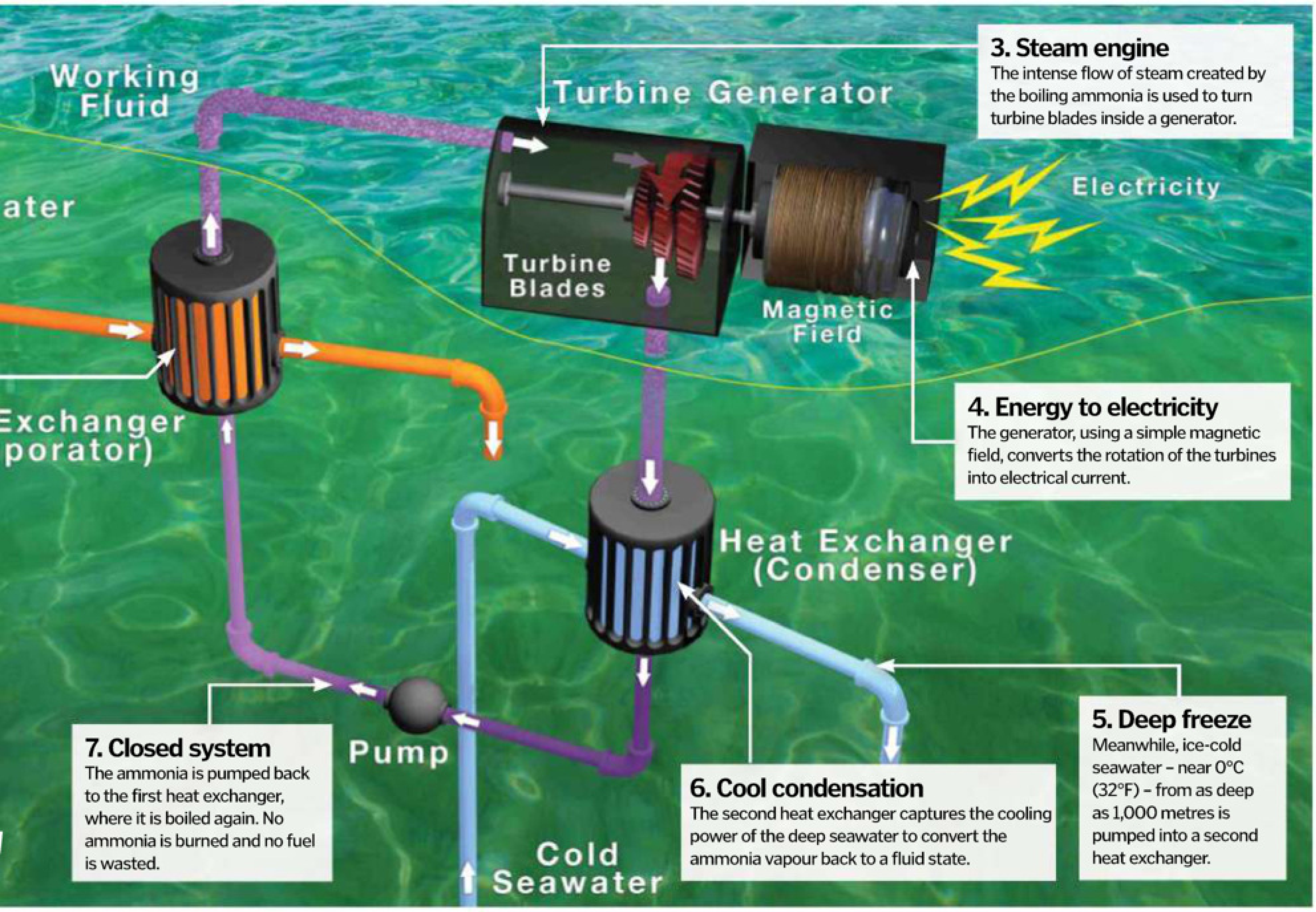


Image © Lockheed Martin

Image © Lockheed Martin



3. Steam engine
The intense flow of steam created by the boiling ammonia is used to turn turbine blades inside a generator.

4. Energy to electricity
The generator, using a simple magnetic field, converts the rotation of the turbines into electrical current.

5. Deep freeze
Meanwhile, ice-cold seawater – near 0°C (32°F) – from as deep as 1,000 metres is pumped into a second heat exchanger.

6. Cool condensation
The second heat exchanger captures the cooling power of the deep seawater to convert the ammonia vapour back to a fluid state.

7. Closed system
The ammonia is pumped back to the first heat exchanger, where it is boiled again. No ammonia is burned and no fuel is wasted.

Image © Lockheed Martin

Head to Head HYDROPOWER

DAMS

1. Tidal power

Hydroelectric power is commonly generated by building a dam (or barrage) across an estuary to store water in a reservoir. The ebb and flow of the tides can be used to turn a turbine to produce electricity. The difference in height between high tide and low tide can also be used to collect the store of water to be released.

WAVES

2. Wave power

The movement of waves over the surface of the ocean can be turned into electricity. Waves travel as crests and troughs, and an object floating on the surface will rise and fall accordingly. This motion can be converted into electricity in a chamber at a wave power station. The rising and falling water causes air to be forced in and out of a hole in the top of the chamber. This air can be used to power a turbine that can generate electricity.

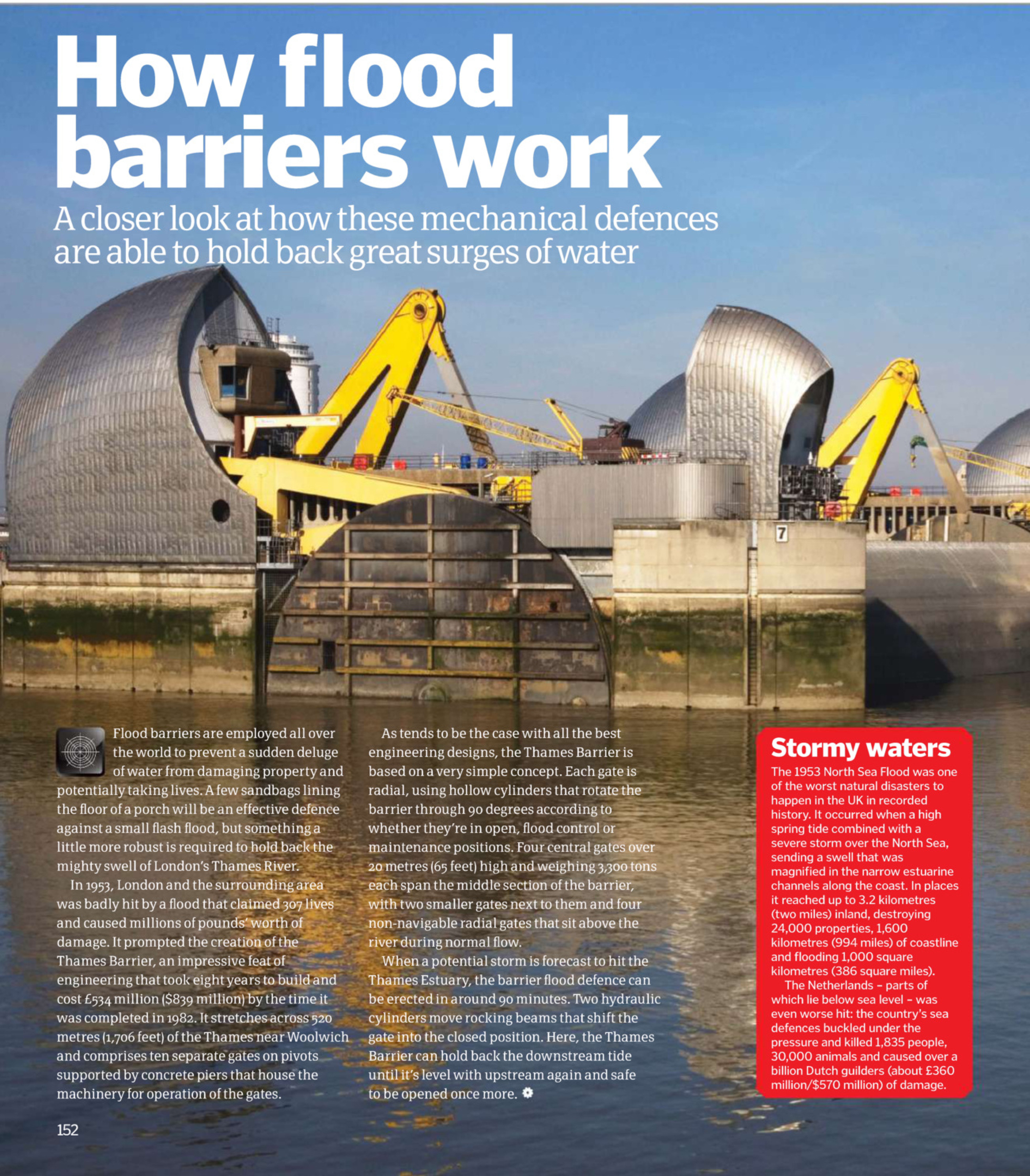
CURRENTS

3. The power of the currents

The power of water can also be harnessed using the oceans' currents. Installing large underwater turbines with rotors capable of turning with the surging movement of ocean currents rushing past can be used to generate clean electricity to nearby coastal areas. The main problem with this form of energy is that the currents need to be strong and the seabed needs to be both shallow and near to the coast.

How flood barriers work

A closer look at how these mechanical defences are able to hold back great surges of water



Flood barriers are employed all over the world to prevent a sudden deluge of water from damaging property and potentially taking lives. A few sandbags lining the floor of a porch will be an effective defence against a small flash flood, but something a little more robust is required to hold back the mighty swell of London's Thames River.

In 1953, London and the surrounding area was badly hit by a flood that claimed 307 lives and caused millions of pounds' worth of damage. It prompted the creation of the Thames Barrier, an impressive feat of engineering that took eight years to build and cost £534 million ($839 million) by the time it was completed in 1982. It stretches across 520 metres (1,706 feet) of the Thames near Woolwich and comprises ten separate gates on pivots supported by concrete piers that house the machinery for operation of the gates.

As tends to be the case with all the best engineering designs, the Thames Barrier is based on a very simple concept. Each gate is radial, using hollow cylinders that rotate the barrier through 90 degrees according to whether they're in open, flood control or maintenance positions. Four central gates over 20 metres (65 feet) high and weighing 3,300 tons each span the middle section of the barrier, with two smaller gates next to them and four non-navigable radial gates that sit above the river during normal flow.

When a potential storm is forecast to hit the Thames Estuary, the barrier flood defence can be erected in around 90 minutes. Two hydraulic cylinders move rocking beams that shift the gate into the closed position. Here, the Thames Barrier can hold back the downstream tide until it's level with upstream again and safe to be opened once more. ✽

Stormy waters

The 1953 North Sea Flood was one of the worst natural disasters to happen in the UK in recorded history. It occurred when a high spring tide combined with a severe storm over the North Sea, sending a swell that was magnified in the narrow estuarine channels along the coast. In places it reached up to 3.2 kilometres (two miles) inland, destroying 24,000 properties, 1,600 kilometres (994 miles) of coastline and flooding 1,000 square kilometres (386 square miles).

The Netherlands – parts of which lie below sea level – was even worse hit: the country's sea defences buckled under the pressure and killed 1,835 people, 30,000 animals and caused over a billion Dutch guilders (about £360 million/$570 million) of damage.

STRANGE BUT TRUE

BRITAIN'S TILTING

Seesaw Britain

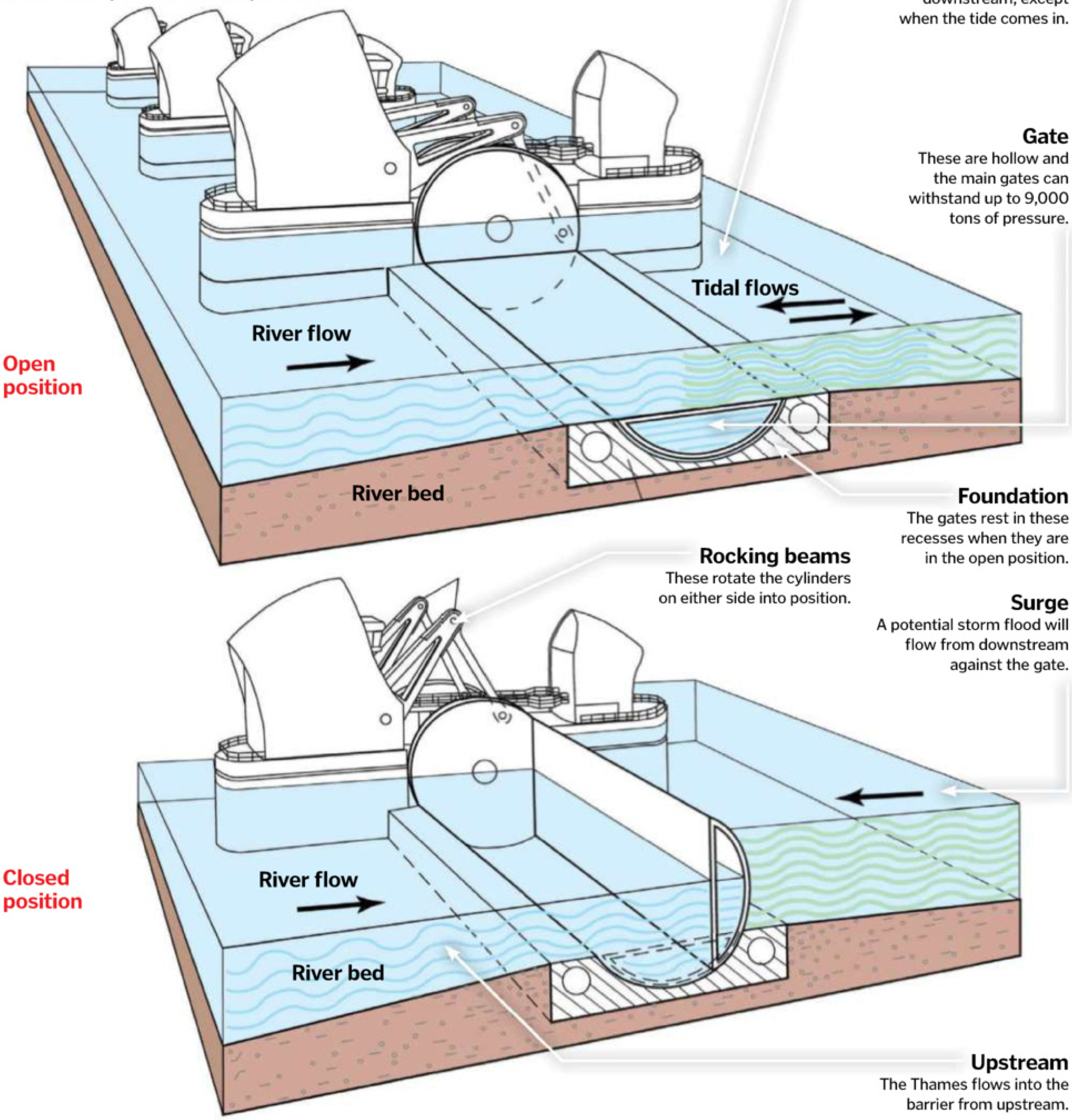
Britain is actually tilting, with the northern and western regions like Scotland and Wales rising, while southern and eastern parts of England are sinking into the sea by 33 centimetres (13 inches) every century.

DID YOU KNOW? *The Thames Barrier was hit by a dredger in thick fog in 1997, causing £13bn ($20.6bn) of damage*

The Thames Flood Barrier has been in operation since 1982 and protects 125km^2 (48mi^2) of central London from tidal surges

The Thames Barrier in action

Explore London's impressive flood defence in both its open and closed positions



Downstream The river flows away from the barrier downstream, except when the tide comes in.

Gate These are hollow and the main gates can withstand up to 9,000 tons of pressure.

Foundation The gates rest in these recesses when they are in the open position.

Rocking beams These rotate the cylinders on either side into position.

Surge A potential storm flood will flow from downstream against the gate.

Upstream The Thames flows into the barrier from upstream.

The biggest barrier

The Oosterscheldekering is the largest movable flood barrier in the world. Like the Thames Barrier, this Dutch feat of engineering was built in response to the 1953 North Sea Flood. It's actually part of 13 dams known as Delta Works and is nine kilometres (5.6 miles) long, four kilometres (2.5 miles) of which include huge sluice-gate doors that are normally open, but can be closed in the event of a tidal surge. It comprises 65 concrete pillars weighing 18,000 tons each, with 62 steel doors, each 42 metres (138 feet) wide. Dutch engineers created an artificial island in the centre of the estuary to facilitate the construction of the structure and, unlike the Thames Barrier, which is estimated to be effective until around 2030, Oosterscheldekering has a predicted lifetime of 200 years.

© v; Thinkstock; Rens Jacobs; John Webber

Ivanpah Solar Power Facility

See how the most advanced solar-powered energy generation site produces electricity

The Ivanpah Solar Power Facility is a brand-new solar thermal power site located in the Mojave Desert in western USA. The facility, which consists of three state-of-the-art thermal power plants lies 64 kilometres (40 miles) south-west of Las Vegas and has a total capacity of 392 megawatts, making it one of the largest of its kind in the world.

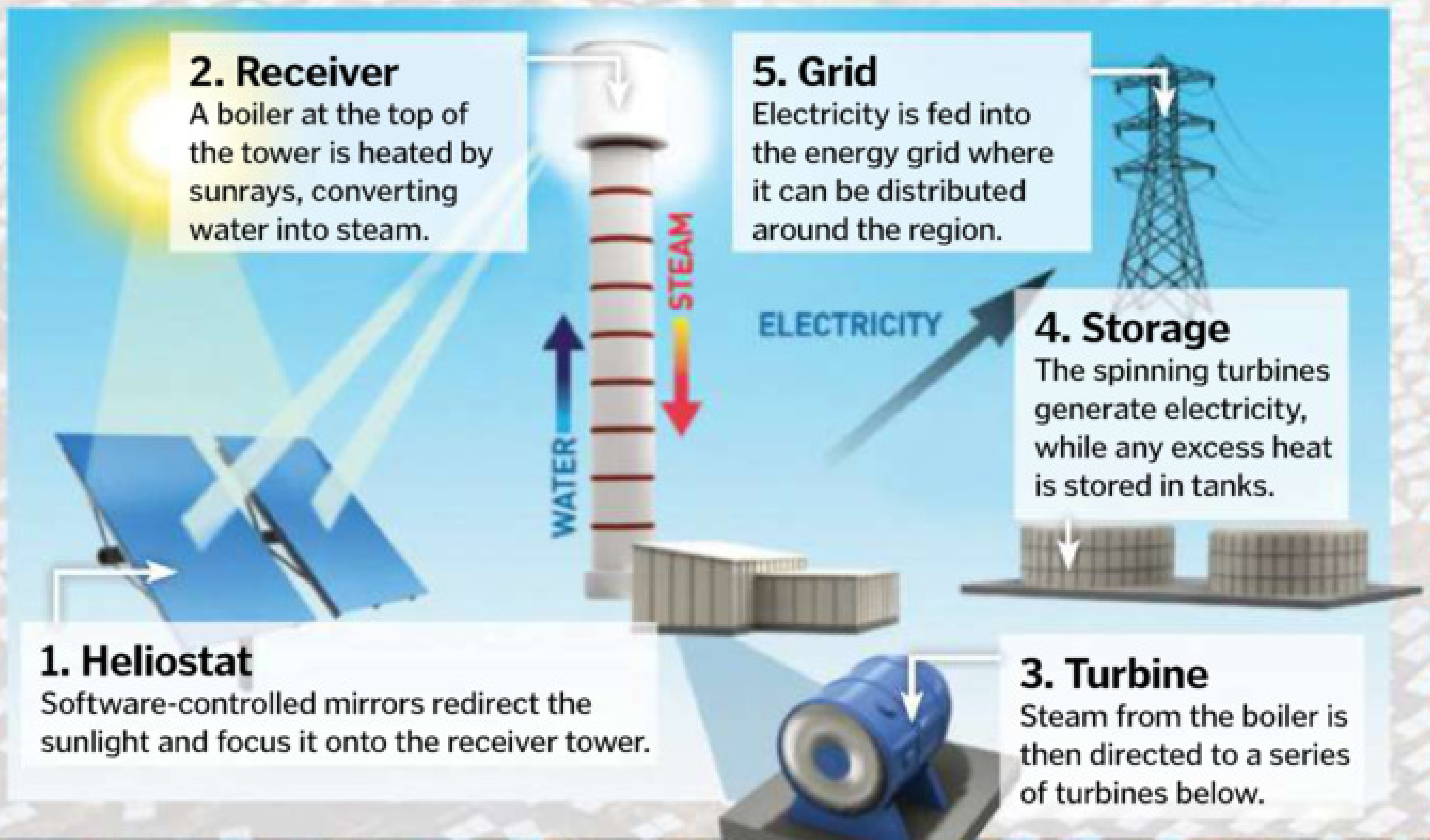
Ivanpah achieves this energy with over 170,000 Sun-tracking heliostats (mirrored panels), which receive a vast quantity of direct sunlight over the 1,415-hectare (3,500-acre) site and redirect it onto steam-producing thermal boilers mounted on top of three receiver towers. This steam is then used directly to power electricity-producing turbines (see 'Ivanpah step-by-step' below to follow the process).

Construction of the Ivanpah project began in October 2010 and is to officially open in the latter part of 2013, with the site set to contribute to California's existing electricity grid.

However, the project has been seen by some environmentalist organisations as controversial due to its construction over an established ecosystem. In particular over 200 desert tortoises needed to be relocated during the build, with a cost of $55,000 per tortoise needed for the move.

Ivanpah step-by-step

From heliostat to energy grid, how does Ivanpah deliver so much power?



1. Heliostat
Software-controlled mirrors redirect the sunlight and focus it onto the receiver tower.

2. Receiver
A boiler at the top of the tower is heated by sunrays, converting water into steam.

3. Turbine
Steam from the boiler is then directed to a series of turbines below.

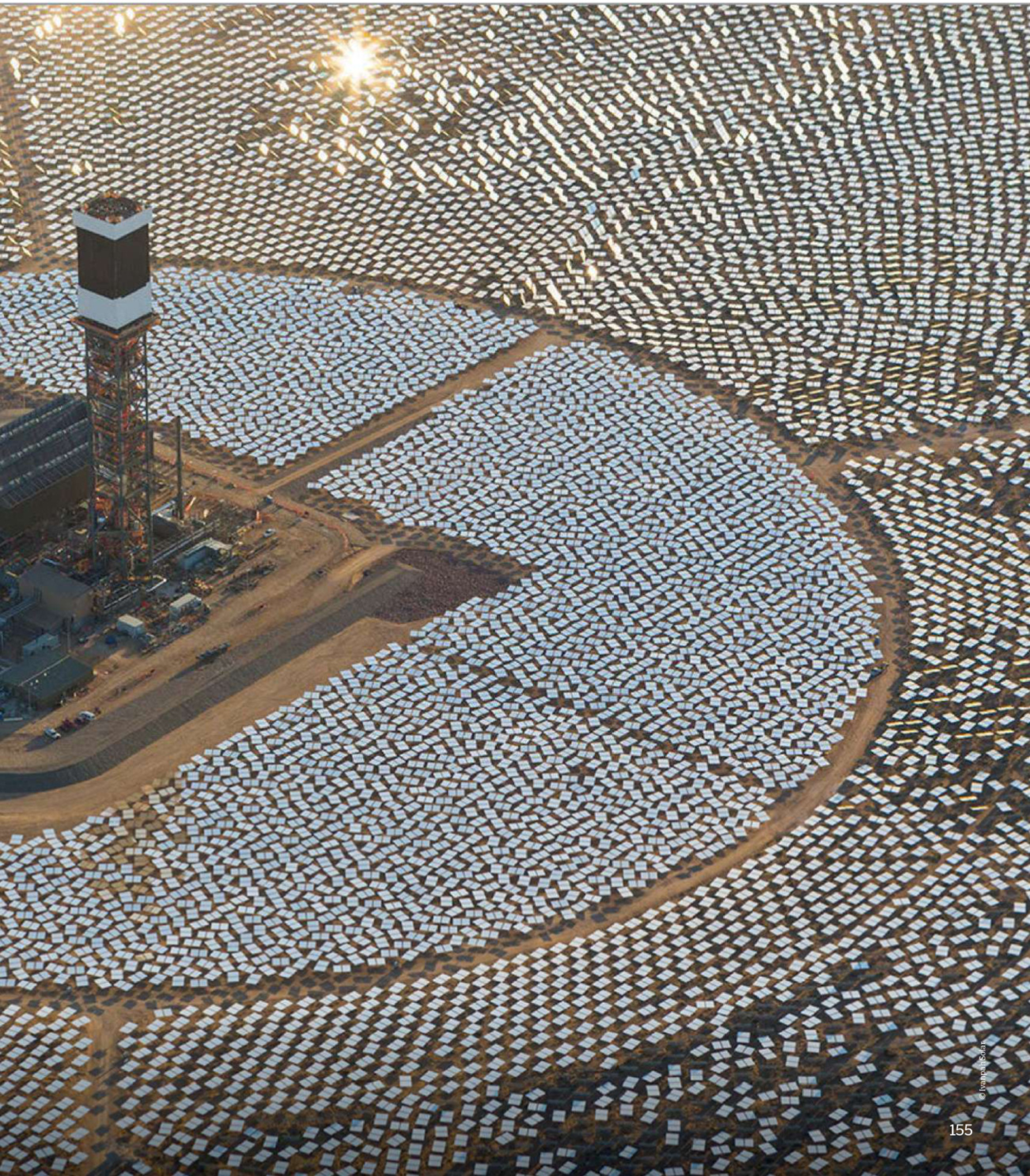
4. Storage
The spinning turbines generate electricity, while any excess heat is stored in tanks.

5. Grid
Electricity is fed into the energy grid where it can be distributed around the region.

THE STATS
IVANPAH FACILITY

HELIOSTATS	173,500	LAND AREA	14.2km^2	REDUCTION IN CO$_2$ (TONS/YR)	400,000
MAXIMUM CAPACITY	392MW	ANNUAL POWER GENERATION	1,079,232MWh	THERMAL PLANTS	3

DID YOU KNOW? *The Ivanpah Solar Power Facility cost in the region of £1.4 billion ($2.2 billion) to build*



© Ivanpah Solar

Snow vehicles

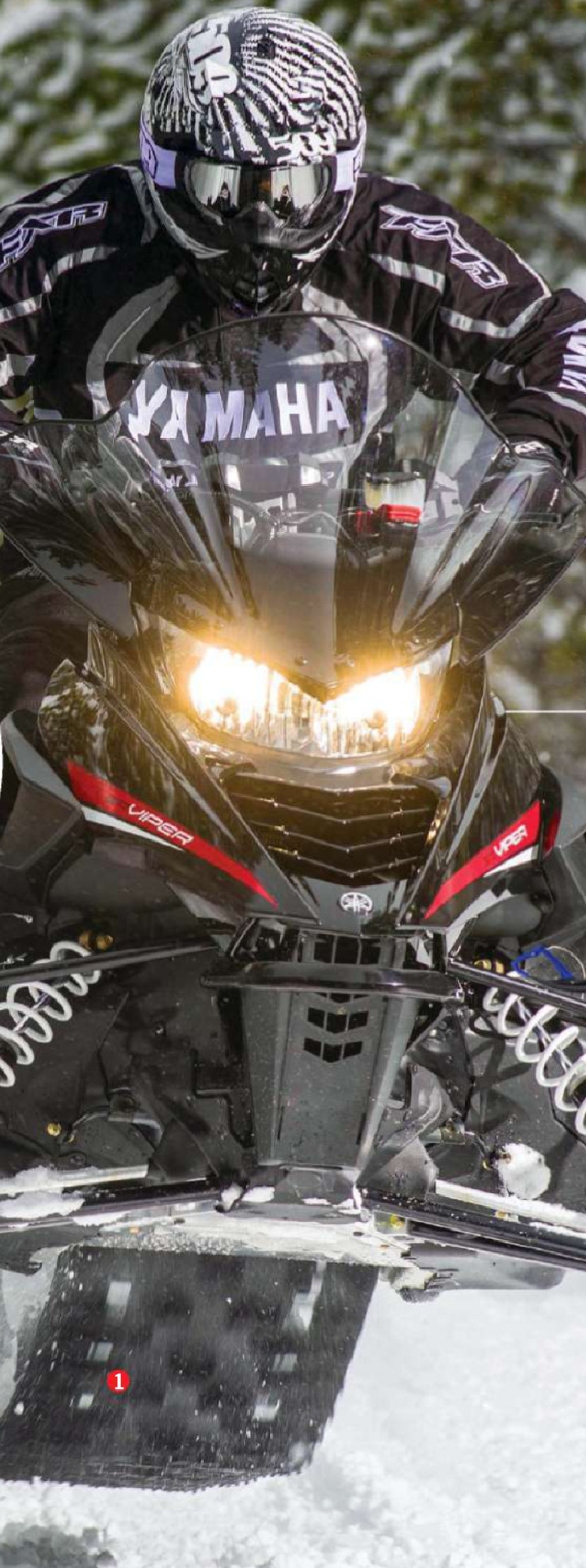
How machines have been engineered to tame even the most extreme winter terrain

In 1958, five years after Edmund Hillary and Sherpa Tenzing Norgay conquered Mount Everest, the relentless Kiwi explorer assisted Dr Vivian Fuchs in a daring land crossing of Antarctica. The expedition was the first to attempt Ernest Shackleton's failed 1914 transantarctic journey, one of the most harrowing survival stories in modern exploration history. Fuchs and his team traversed some of the most impassable terrain on Earth – littered with treacherous crevasses and ice-capped mountain ranges – to cross the whole of the frozen continent, some 3,473 kilometres (2,158 miles), in 99 days. But Fuchs, who was immediately knighted for his achievement, had an advantage over Shackleton and his stranded compatriots: a Sno-Cat. Even better, he had four of them.

The Sno-Cat was invented in the Forties by American EM Tucker, who for decades dreamed of a tracked snow vehicle capable of crossing the deepest snow and roughest ice. Modern Sno-Cats maintain Tucker's 1958 design for the transantarctic expedition: four independent tracks, each swivel-mounted on the drive axle to maintain firm contact with the ground over uneven terrain. In addition to old-school steel tracks, today's Sno-Cats include the option of all-rubber tracks that offer tremendous traction and longer service life. Sno-Cats remain some of the only vehicles in the world capable of reaching Arctic mining rigs and attempting deep-powder search-and-rescue missions.

The Sno-Cat is the master of traction, the greatest engineering challenge to ice and snow transport. To provide traction on slick surfaces, you need what engineers call 'bite'. The hundreds of steel or rubber teeth on a Sno-Cat or snowmobile track serve as multiple biting edges. Each edge is angled and positioned to provide a

Vivian Fuchs (above) at the South Pole with his Sno-Cat



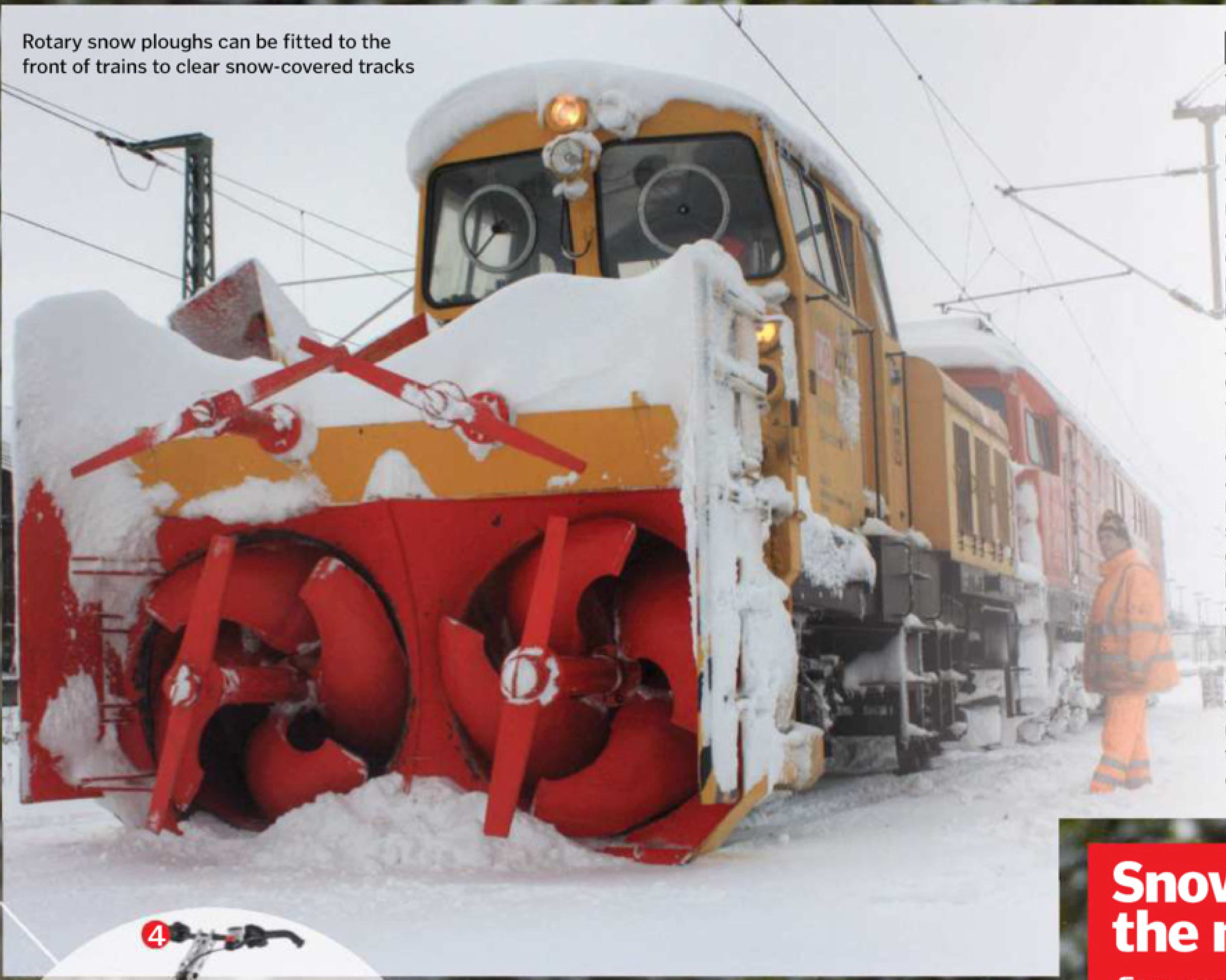
RECORD BREAKERS
TAKING A FLYER

125.6m

WORLD'S LONGEST SNOWMOBILE JUMP

In 2011, American snowmobiler Levi LaVallee broke his own world record on a snow-free ramp in San Diego, CA, to cover 125.6m (412ft). He jumped simultaneously with a motorbike, which 'only' flew for 115m (378ft).

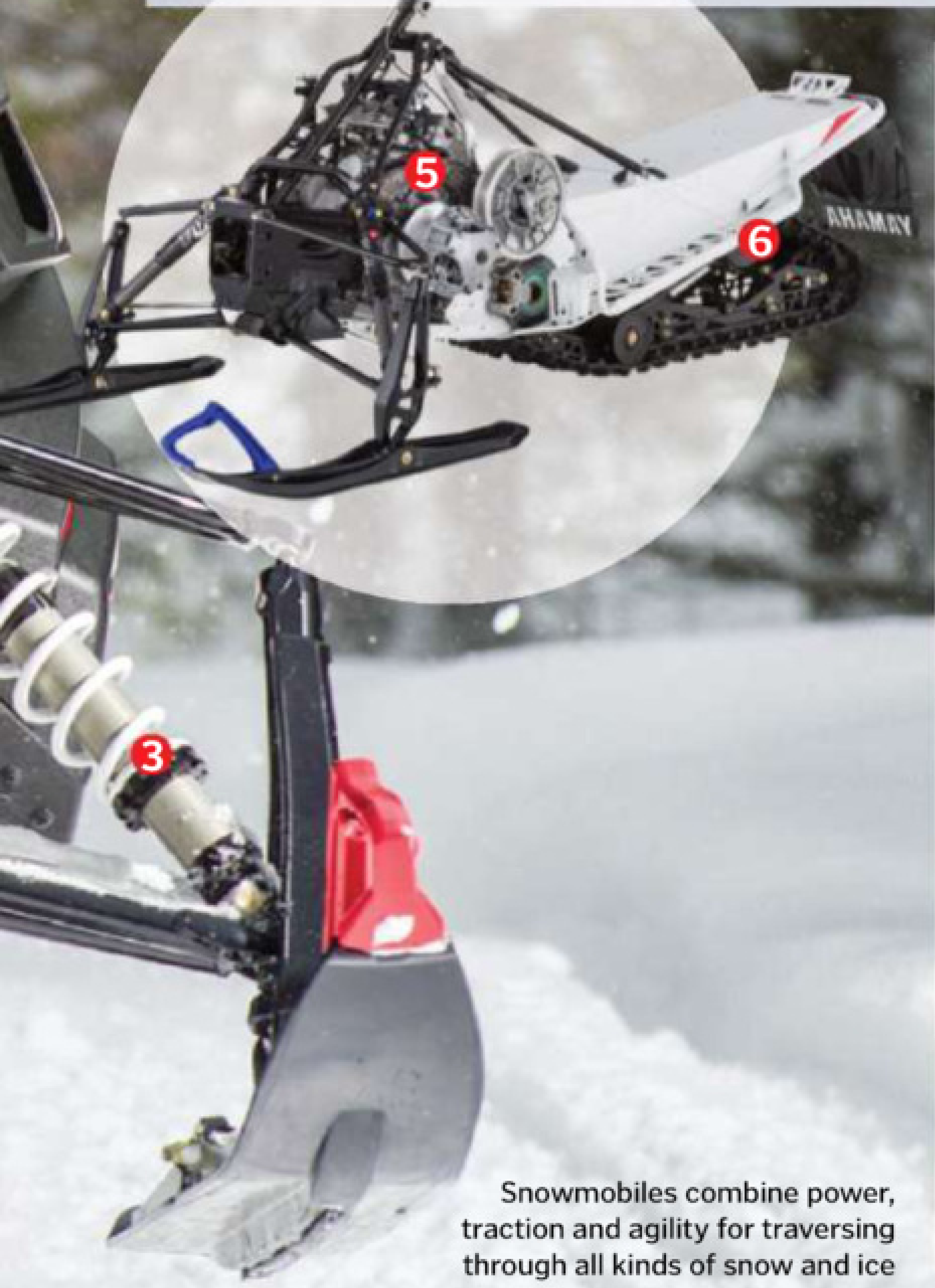
DID YOU KNOW? *Champion snowshoe racers can complete a 10km (6.2mi) course in under an hour*



Rotary snow ploughs can be fitted to the front of trains to clear snow-covered tracks

Ploughs in focus

The first snow ploughs were horse-drawn sleighs mounted with an iron or wooden wedge (see below right). Today, ploughs are engineered for speed and efficiency. Truck-mounted ploughs feature hydraulic arms to adjust for blade height, discharge direction and road pressure. A recent innovation is to pair the conventional front plough with a second side-mounted blade that creates a wider plough path and ejects snow farther off the road. The first rotary snowblowers were invented in the late-19th century to clear railroad tracks impassable with a traditional wedge plough. The rotary snowblower works by scooping snow into its giant rotating fan blades – each around two metres (6.6 feet) long – which force the snow upward through an exhaust chute.



Snowmobiles combine power, traction and agility for traversing through all kinds of snow and ice

How snowmobiles combat the snow

The 2014 Yamaha SR Viper sports power, precision handling and comfort

① Tracks
Called lugs, the tracks' teeth are angled for maximum bite in both hard-packed snow and powder.

② Skis
Plastic trail skis are wide and stiff with a ridge along the length of the keel for greater traction during turns.

③ Shocks
Gas shocks with coil springs plant skis firmly on the snow surface, even in bumpy conditions.

④ Brakes
The hydraulic braking system is activated at the handlebars to clamp down on a 20cm (8in) rotor.

⑤ Engine
The muscle of the Yamaha SR Viper is an electric-start, four-stroke, three-cylinder engine.

⑥ Rear suspension
Two shock absorbers provide 34.3cm (13.5in) of rear suspension for a smoother ride.

⑦ Heated grips
Deluxe snowmobiles include amenities like heated handgrips, thumb warmers and an adjustable heated seat to mitigate sub-zero temperatures.

Snow vehicles by the numbers

Snowmobile

Speed: 75km/h (47mph)
Capacity: 1-2 people
Cost: £4,900-£9,200 ($8,000-$15,000)

Icebreaker

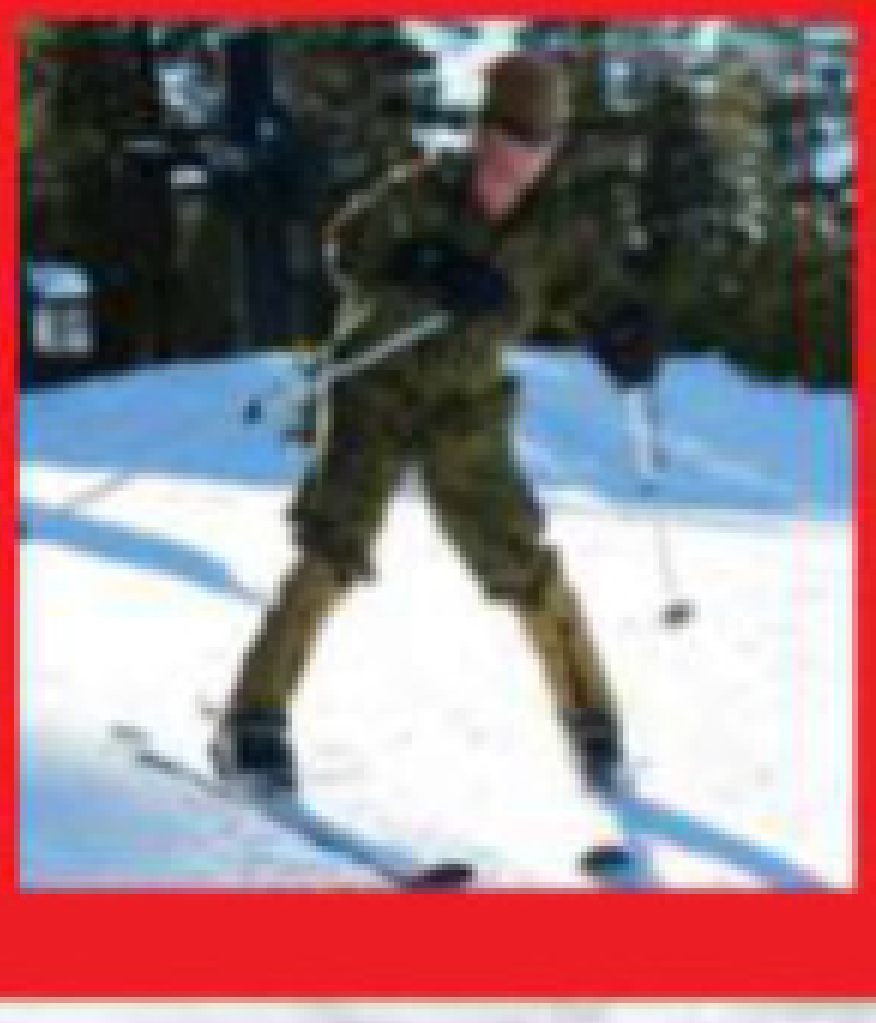
Speed: 1.5 knots (2.8km/h; 1.7mph)
Capacity: 140 people
Cost: £610mn ($1bn)

Dog sled

Speed: 40km/h (25mph)
Capacity: 1 musher; 12 dogs
Cost: £180-£600 ($300-$1,000) for sled; £9,200 ($15,000) to lease dogs for a year

Downhill skis

Speed: 64km/h (40mph)
Capacity: 1 person
Cost: £180-£600 ($300-$1,000)



specific type of traction. For grooming deep snow, long and straight steel tracks offer the best grip. To avoid slippage on steep side hills, rubber-biting edges are arranged in a zigzag pattern to provide traction in multiple directions at once. But for maximum speed and control on ice, nothing beats sharp metal studs that can cut into the frozen surface.

In contrast, one of the fastest ways to travel across snow-packed terrain is to abandon traction altogether. Skis and snowboards are designed to minimise friction, using slick polyethylene plastic and fresh applications of wax across the base of the board while still maintaining control with sharpened edges.

To lend them strength and stiffness, skis and snowboards are built around a hardwood core sandwiched between layers of fibreglass. The individual glass strands in the fibreglass are angled at 45 degrees, 0 degrees and -45 degrees to increase torsional stiffness – a measure of how much a material can twist.

Hovercrafts take frictionless snow travel to a whole new level, using large fans to force air underneath the vehicle's platform where it's contained by a flexible skirt. The pressure created by the trapped, circulating airflow is enough to lift the platform off the difficult terrain altogether, allowing the vessel to cruise friction-free over the deepest drifts of soft snow or thinnest lake ice. Hovercrafts sacrifice braking and handling for free-floating power, so if you're going to try hovering on snow, stick to large open fields or frozen lakes and leave the forested mountain trails to snowmobiles.

Snowmobiles combine the traction of a Sno-Cat with the speed and manoeuvrability of a skier. A single-studded track in the back provides forward thrust while a pair of swivelling skis up front provide low-friction steering. The tracks are custom-engineered in a wide variety of configurations to handle diverse snow conditions and riding styles.

For instance, trail riders look for tracks with steel studs for ice and medium-height teeth (called lugs) that rip into hard-packed snow. Cross-country and mountain riders, who need maximum traction and control in deep powder, want tracks with extra-tall lugs – ie five to 7.6 centimetres (two to three inches). Snowmobile racers compete on compacted snow, so racing lugs are made from extra-hard compounds that increase bite strength for greater thrust. There are even super-smooth, lugless street-racing snowmobile tracks for asphalt drag races.

Many ski resorts and national parks now court snow-loving tourists with snow coach tours. A snow coach is a heavily modified mashup of a snowmobile and a 30-passenger van. Like a snowmobile, the snow coach has a pair of massive tracks in the back and either two oversized skis or two additional tracks in the front. The tracks are powered by replacing the two back wheels of the coach with heavy-toothed gears. As torque is applied, the track is driven forward, powering the vehicle through deep powder for unspoiled, off-the-track views of remote peaks and winter wildlife.

Lighter trucks are getting in on the winter mod craze too. If winter tyres don't offer enough deep-tread traction, you can buy a set of four wheel-mounted tracks that can be attached and removed in 15 minutes. This innovative system doesn't require heavy modifications. In fact, the wheels power the tracks. Each wheel on a

The power of icebreakers

Icebreakers – those massive vessels that cut paths through frozen seas – should really be called ice smashers. An icebreaker's bow is wide and round like the bottom of a bathtub. Icebreakers don't slice through sea ice with a razor-sharp nose, as you might expect. They use that smooth, rounded bow to glide on top of the ice and crush it into pieces with the ship's tremendous weight. To smash through a particularly thick section of ice, the captain will back up and bring the vessel to full ramming speed.

The world's biggest icebreakers run on nuclear power to provide constant thrust without need for refuelling in remote locations. Dual-functioning ships have a conventional sharp bow to navigate on the high seas, but when operating in reverse, the ship's propeller agitates the water beneath the ice while the rounded rear of the hull slides over and smashes through the ice sheet. Even icebreakers can get snared by thick ice floes though, as demonstrated by the Chinese icebreaker Xue Long, which got trapped near Antarctica in 2013.

Icebreakers carve paths through ice for other ships

DID YOU KNOW? *During the 1,600km (1,000mi) Iditarod race, sled dogs need to consume 10,000 calories a day!*

standard 4x4 pickup truck runs atop what looks like a small treadmill. The wheels snap into place between four tight-fitting rollers and can drive the tracks both forward and backward. Flexible ski tips on the front and back of each track help them climb tall snowdrifts and navigate down steep slopes.

More than 50 years after Fuchs and Hillary traversed the Antarctic in a squadron of Sno-Cats, the British Antarctic Survey (BAS) continues to study the past and present of the polar ice sheets for clues to our planet's climatic future.

The BAS relies on tracked trucks, cranes and tractor-mounted snowblowers to tame the extreme terrain. A two-person snowmobile proposed by BAS (known as Ninety Degrees South) features two wide, near-spherical wheels up front instead of skis, for stability. There are six knobbly treads along the rims for traction and the rear tracks are mounted on a large, Z-shaped, spring-loaded shock absorber. Perhaps its coolest innovation yet is a unit that travels 30 metres (98 feet) ahead of the snowmobile on a cord, using ground-penetrating radar to scan the ice for dangerous hidden crevasses.

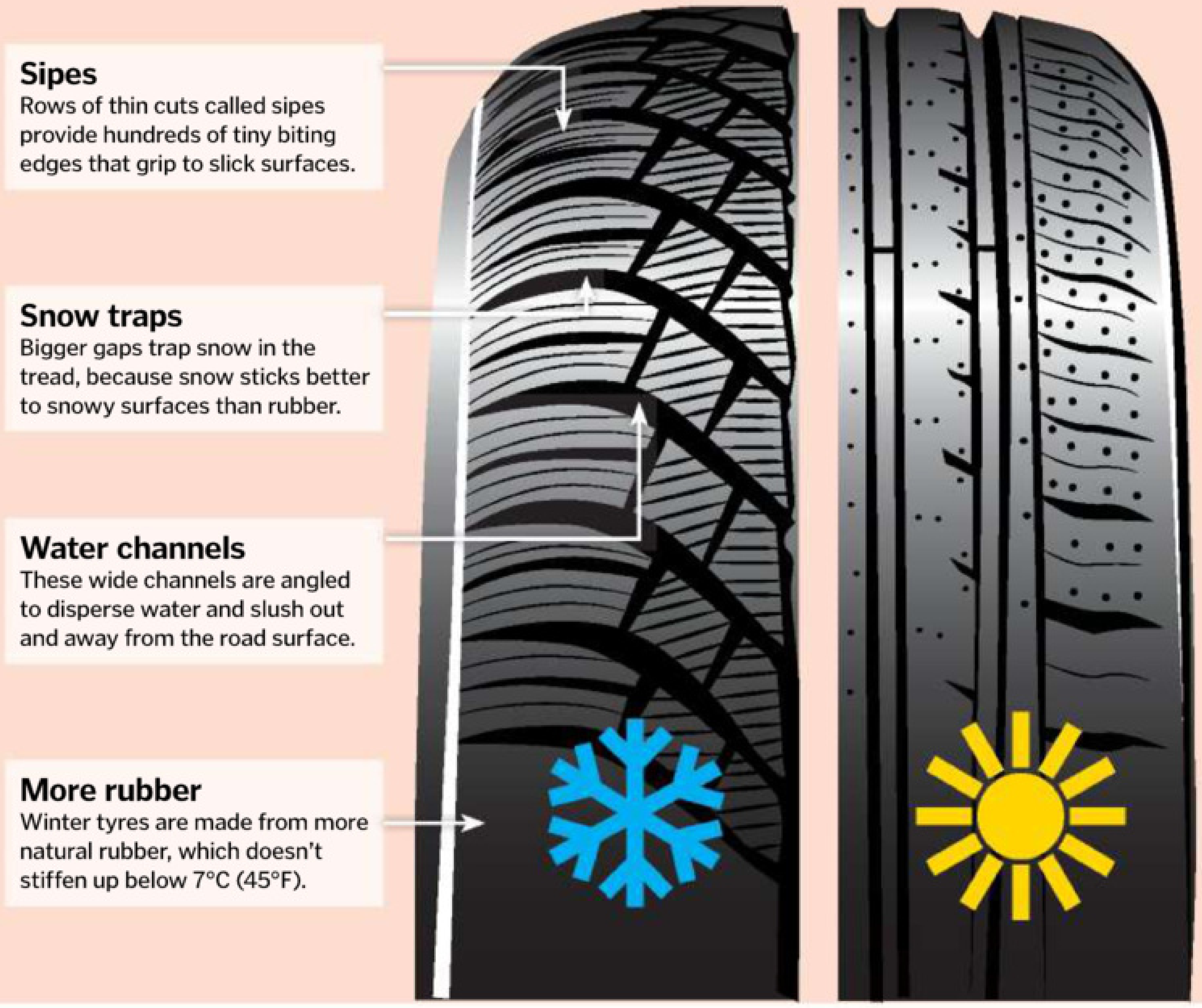
Snow travel without an engine

Starting 10,000 years ago, humans relied on snowshoes and skis to migrate and hunt across vast stretches of frozen wilderness. The physics of snowshoes is simple – a larger surface area distributes the weight, preventing you from breaking the surface and sinking.

Skis employ the same physics, but also add the dimension of speed. Skis are polished and waxed to decrease friction and edges are sharpened for more efficient turns. Dog sleds combine the speed of skis with the genetic superiority of sled dogs and their relentless urge to run. In the case of dogs like Siberian huskies, fur comes in layers in order to trap heat, so they can withstand temperatures as low as -60 degrees Celsius (-76 degrees Fahrenheit). Hair between the dogs' toe pads provides extra traction on slippery surfaces.

Winter tyres vs summer tyres

What are the key differences between these seasonal tyres?



Sipes
Rows of thin cuts called sipes provide hundreds of tiny biting edges that grip to slick surfaces.

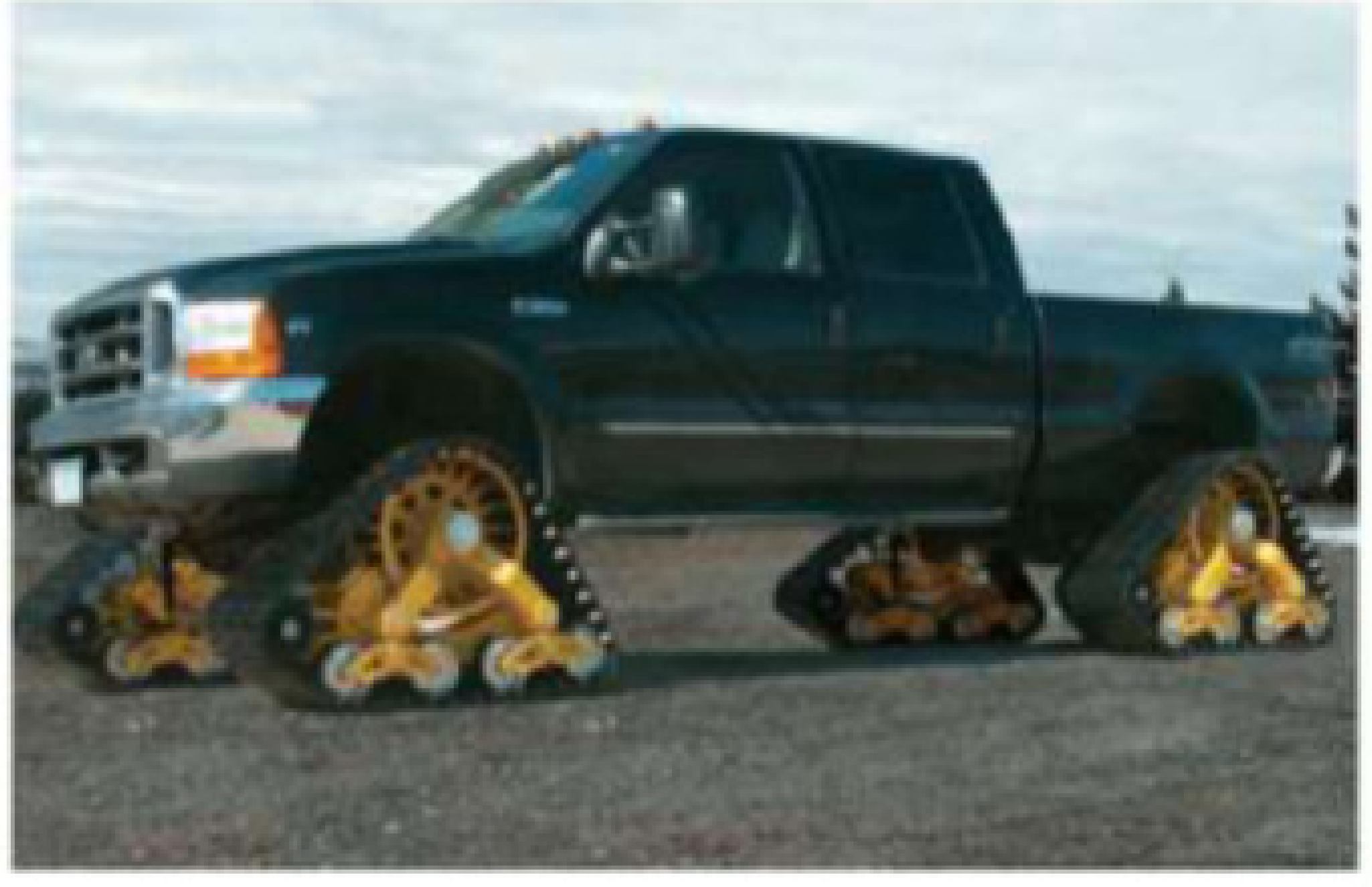
Snow traps
Bigger gaps trap snow in the tread, because snow sticks better to snowy surfaces than rubber.

Water channels
These wide channels are angled to disperse water and slush out and away from the road surface.

More rubber
Winter tyres are made from more natural rubber, which doesn't stiffen up below 7°C (45°F).

Winter mods

In parts of the world, driving through deep snow and over treacherous ice is a part of everyday life. The first line of attack is winter tyres. These are made from more natural rubber than all-season tyres which remains soft at lower temperatures than synthetics. The channels between the tread are deeper and wider to displace water and trap snow; as it turns out, snow sticks better to a snow-covered road than rubber. Tiny cuts (sipes) provide improved traction on ice by increasing the number of biting edges. Snow chains, wrapped tightly around the tyre, cut deeply into snow and ice to provide serious traction, but must be removed on cleared roads as to not damage the surface. An innovation for emergency vehicles is OnSpot, a push-button chain system that spins a wheel of chains between the tyre and the snow. Then there are new track systems that convert pickup trucks into snowmobiles. Mattracks (pictured) replace tyres with four track units powered by the front and rear axles, while the Track N Go system is more like two pairs of tracked shoes that can be fitted and removed in minutes and the tyres are what rotate the tracks.



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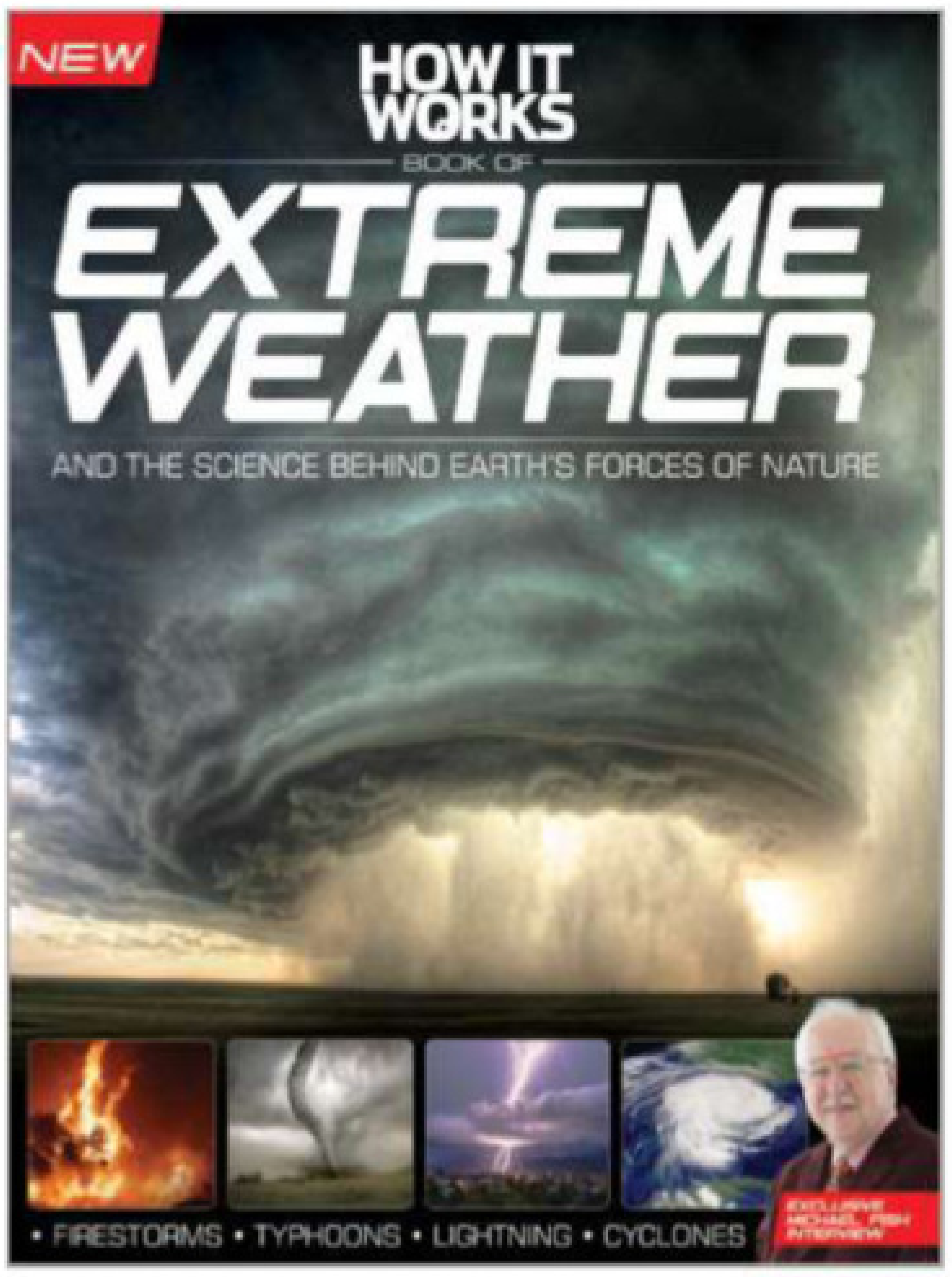
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